Spaceborne Synthetic Aperture Radar (SAR) Mapping

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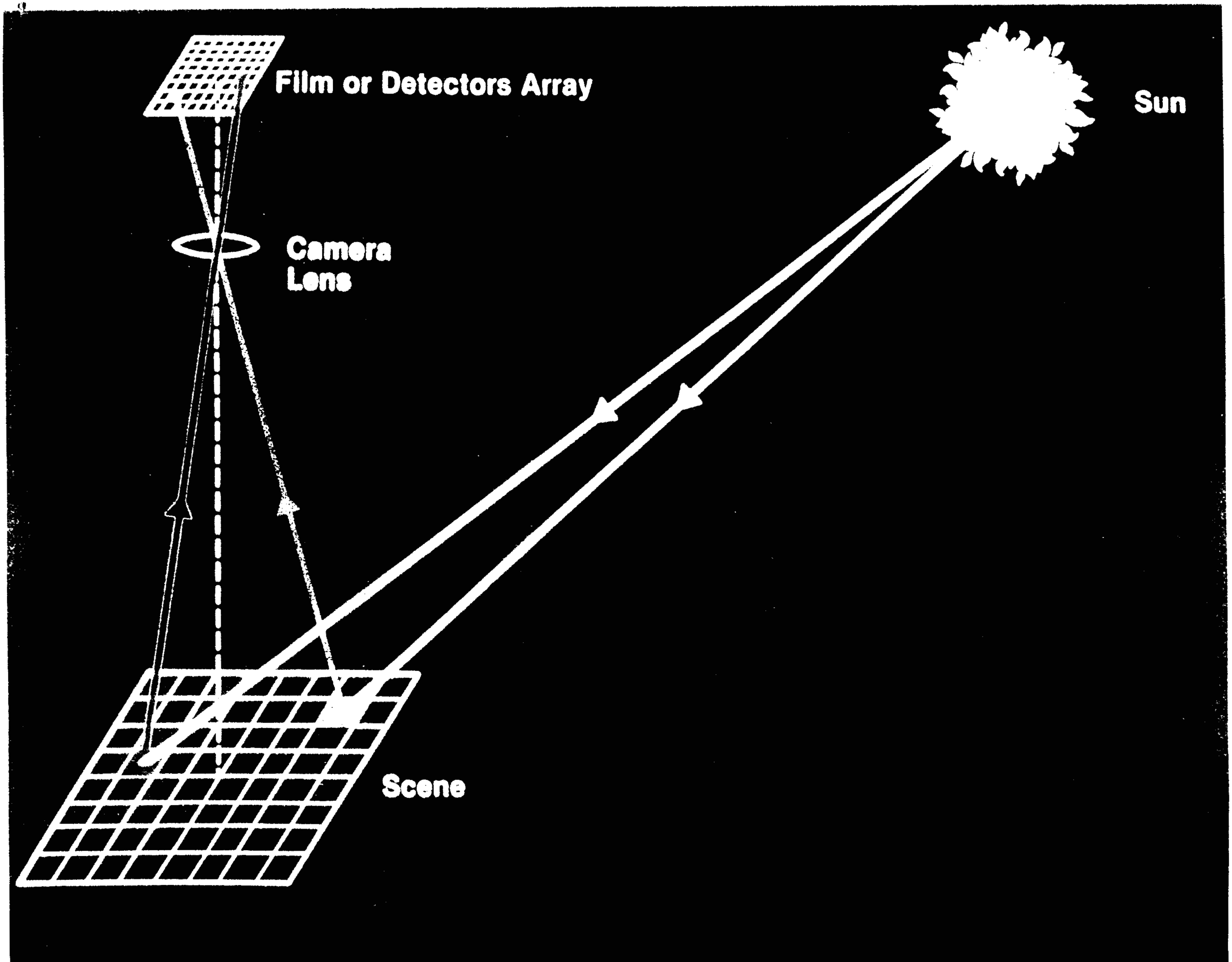
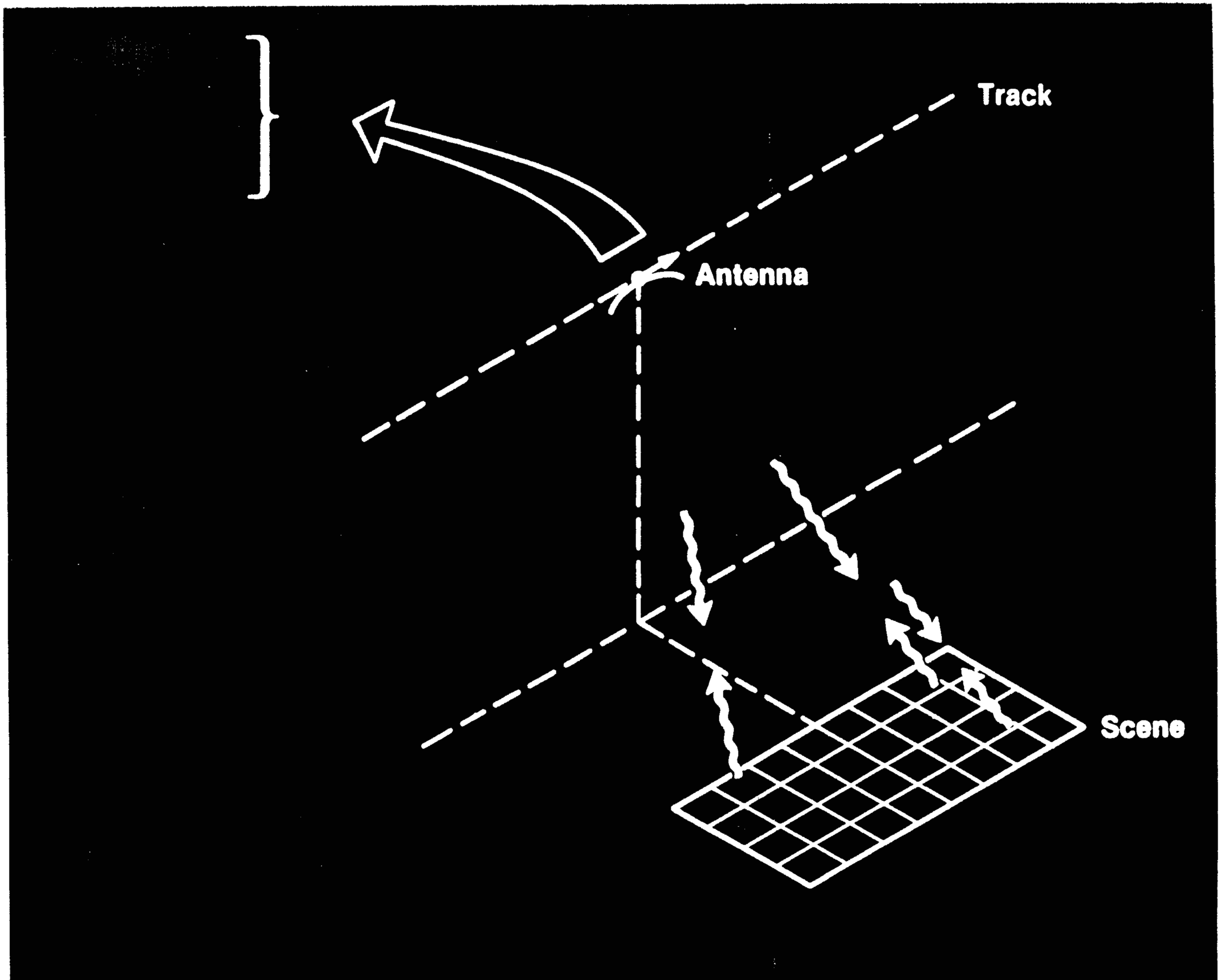
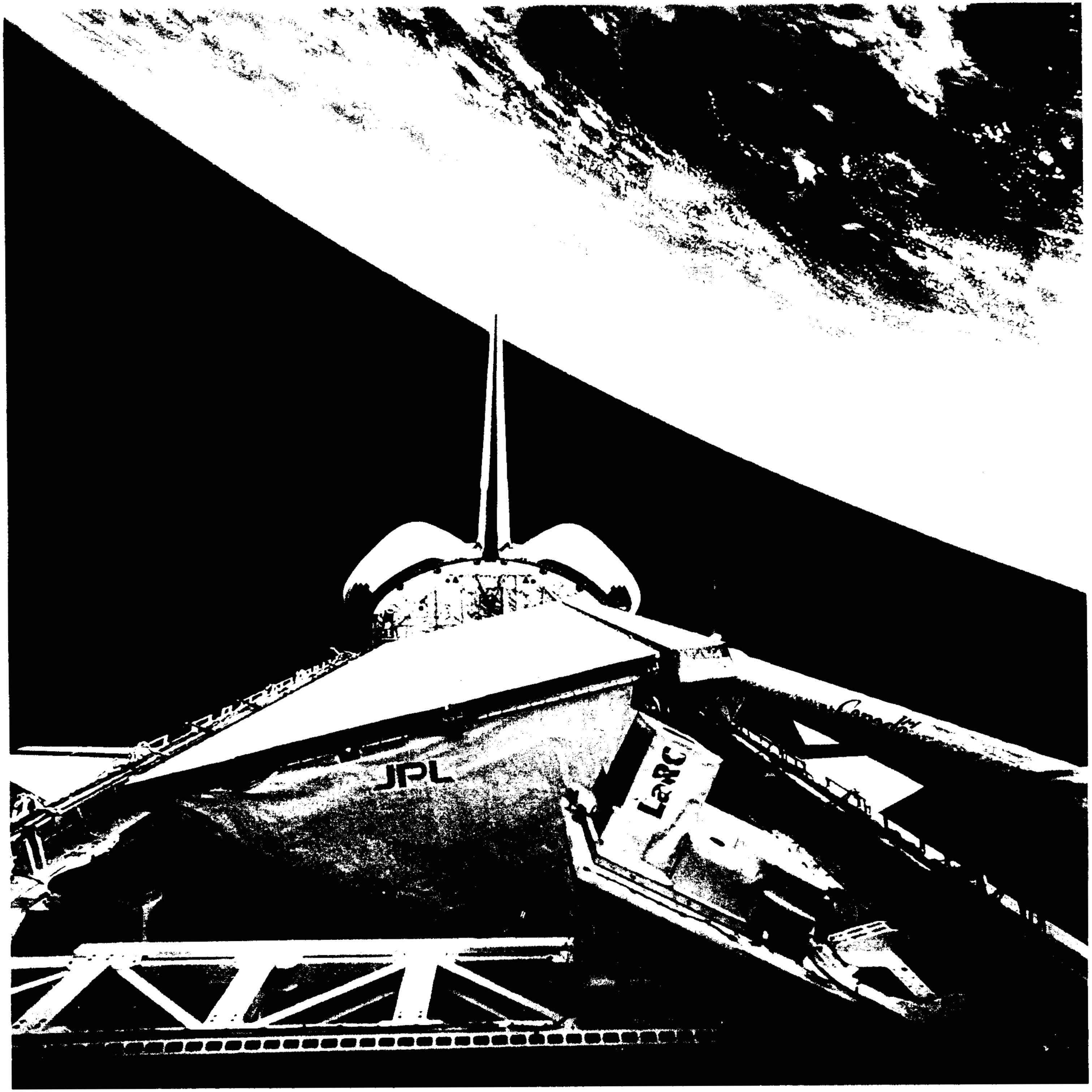


How Cameras Work



How Imaging Radar Works


JPL
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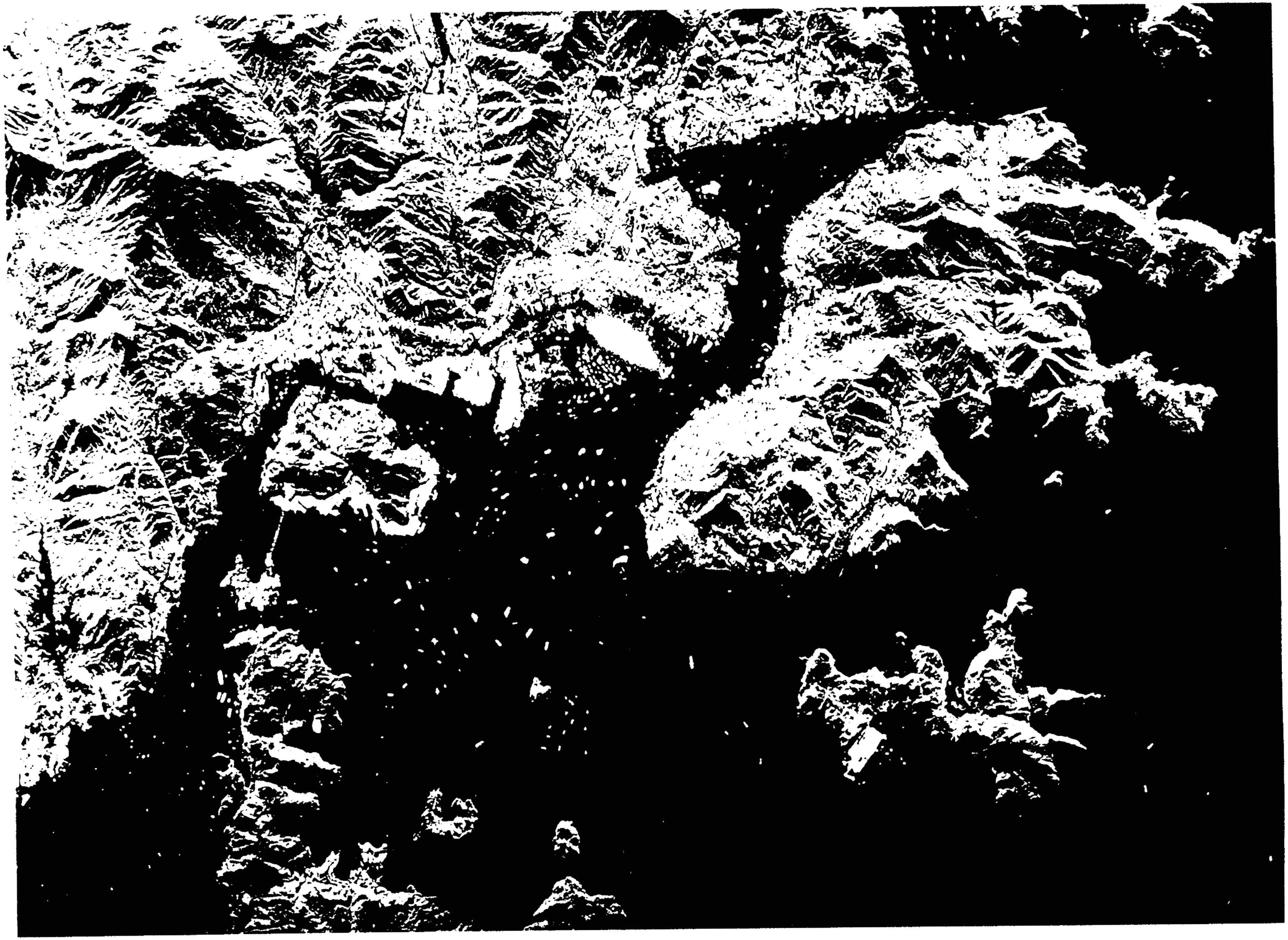

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PHOTO CAPTION

P-46983
June 13, 1996
Hong Kong
L & C bands

This spaceborne radar image shows part of the British territory of Hong Kong, adjacent to mainland China. The South China Sea is shown in dark blue and red on the image. Land surfaces are seen in shades of lighter blue and gold, including Hong Kong Island in the lower center, the Kowloon Peninsula in the upper right and many other small islands. The brightest yellow areas are the densely developed areas of Hong Kong's business and residential districts. The small yellow dots in the water are the many ships that make Hong Kong one of the busiest seaports in the Far East. Images such as this can be used by land use planners to monitor urban development and its effect on the tropical environment. The image was acquired by the Spaceborne Imaging Radar-C/X-Band Synthetic Aperture Radar (SIR-C/X-SAR) onboard the space shuttle Endeavour on October 10, 1994. The image is 23 kilometers by 31 kilometers (14 miles by 19 miles) and is centered at 22.3 degrees North latitude, 114.1 degrees East longitude. North is toward the upper right. The colors are assigned to different radar frequencies and polarizations of the radar as follows: red is L-band, vertically transmitted and received; green is C-band, vertically transmitted and received; and blue is C-band minus L-band, both vertically transmitted and received. SIR-C/X-SAR, a joint mission of the German, Italian, and United States space agencies, is part of NASA's Mission to Planet Earth.

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PHOTO CAPTION

P-46293
October 26, 1995
Oil Slicks

This is a radar image of an offshore drilling field about 150 km (93 miles) west of Bombay, India in the Arabian Sea. The dark streaks are extensive oil slicks surrounding many of the drilling platforms, which appear as bright white spots. Radar images are useful for detecting and measuring the extent of oil seepages on the ocean surface, from both natural and industrial sources. The long, thin streaks extending from many of the platforms are spreading across the sea surface, pushed by local winds. The larger dark patches are dispersed slicks that were likely discharged earlier than the longer streaks, when the winds were probably from a different direction. The dispersed oil will eventually spread out over the more dense water and become a layer which is a single molecule thick. Many forms of oil, both from biological and from petroleum sources, smooth out the ocean surface, causing the area to appear dark in radar images. There are also two forms of ocean waves shown in this image. The dominant group of large waves (upper center) are called internal waves. These waves are formed below the ocean surface at the boundary between layers of warm and cold water and they appear in the radar image because of the way they change the ocean surface. Ocean swell, which are waves generated by winds, are shown throughout the image but are most distinct in the blue area adjacent to the internal waves. Identification of waves provide oceanographers with information about the smaller scale dynamic processes of the ocean. This image was acquired by the Spaceborne Imaging Radar-C/X-Band Synthetic Aperture Radar (SIR-C/X-SAR) aboard the space shuttle Endeavour on October 9, 1994. The colors are assigned to different frequencies and polarizations of the radar as follows: Red is L-band vertically transmitted, vertically received; Green is the average of L-band vertically transmitted, vertically received and C-band vertically transmitted, vertically received; Blue is C-band vertically transmitted, vertically received. The image is located at 19.25 degrees north latitude and 71.34 degrees east longitude and covers an area 20 km by 45 km (12.4 miles by 27.9 miles). SIR-C/X-SAR, a joint mission of the German, Italian, and the United States space agencies, is part of NASA's Mission to Planet Earth.

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OCEAN EDDIES AT ICE MARGIN IN WEDDELL SEA

JPL

ALASKA SAR FACILITY RADARSAT SIMULATED SCANSAR PRODUCT USING SIR-C DATA

OCTOBER 5, 1994

56.6°S 6.5°W

50 km

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PHOTO CAPTION

P-46021BC
Weddell Sea

This radar image shows two large ocean circulation features called eddies at the northernmost edge of the sea ice pack of the Weddell Sea, off Antarctica. The eddy processes in this region play an important role in the circulation of the global ocean and the transportation of heat toward the pole. This is the first wide-swath multi-frequency, multi-polarization radar image ever processed. To date, no other spaceborne radar sensors have obtained swaths exceeding 100 kilometers (62 miles) in width. This developmental image was produced at NASA's Jet Propulsion Laboratory by the Alaska SAR Facility's ScanSAR processor system using radar data obtained on October 5, 1994 during the second flight of the Spaceborne Imaging Radar C/X-Band Sythetic Aperture Radar onboard the space shuttle Endeavour. The image is oriented approximately east-west, with a center location of around 56.6 degrees South and 6.5 degrees West. Image dimensions are 240 kilometers by 350 kilometers (149 miles by 218 miles). The ocean eddies have a clockwise (or cyclonic) rotation and are roughly 40 to 60 km (25 to 37 miles) in diameter. Small sea-ice floes that are swept along by surface currents, are shown both within the eddies and to the south of the eddies in this image. Several distinct forms of sea ice are visible including grease ice (a slushy viscous form of new ice) which appears smooth and dark on the radar image; pancake ice, typically small, 1 to 2 meter (3 to 7 feet) diameter rounded ice floes formed by the clumping of grease ice under waves, which appears bright in the radar image and filamentous (lighter green); and first-year, seasonal ice, typically 0.5 to 0.8 meter (1.5 to 2.5 feet) thick, seen in the lower right corner as darker green color. The open ocean to the north is uniformily bright due to high winds making the surface rough. The colors in this image were obtained using the following radar channels: L-band vertical transmit-vertical receive (VV) is blue, L-band horizontal transmit-vertical receive (HV) is green, and C-band VV is red. The ScanSAR processor is being designed for 1996 implementation at NASA's Alaska SAR Facility, located at the University of Alaska Fairbanks, and will produce digital images from the forthcoming Canadian RADARSAT satellite, whose C-band HH (horizontal transmit-horizontal receive) polarization radar will operate in a wide-swath (300 to 500 kilometer/186 to 310 mile) mode. In order to test the processor for this example, a wide-swath (over 200 kilometer/125mile) data set from the SIR-C/X-SAR flights was used.

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PHOTO CAPTION

P-47974
October 24, 1996
Palm Valley, Australia
L & C bands

This spaceborne radar image shows mountains and valleys in the arid landscape of central Australia. The mountains are part of the MacDonnell Ranges in the Northern Territory of Australia, just west of the town of Alice Springs. The prominent linear and curving bands are outcrops of sedimentary rocks that have been folded and tilted during ancient episodes of mountain building. These rock layers provide traps for natural gas, which is currently being extracted from this area for commercial use. The dark brown and blue area in the center of the image is a broad valley covered with recent gravel sediments and grasses. The Finke River cuts across the mountain ridge in the upper right, and continues in a deep canyon in the lower center of the image. Above and to the left of the river canyon is a broad oval-shaped valley with blue patches. This is Palm Valley, which contains rare species of palms, some of which can be traced back, virtually unchanged, in the fossil record more than 50 million years. Scientists are using radar data of this region in studies of oil and gas exploration, landscape and soil evolution, and plant ecology.In a joint program between NASA and several South Pacific and Asian countries including Australia, high resolution radar images and topography data are to be collected by JPL's Airborne Synthetic Aperture Radar (AIRSAR) onboard a NASA DC-8 aircraft in the fall of 1996 to give scientists a more detailed view of the region. This image was acquired by the Spaceborne Imaging Radar-C/X-band Synthetic Aperture Radar (SIR-C/X-SAR) onboard the space shuttle Endeavour on April 13, 1994. The image is 90.4 kilometers by 59.8 kilometers (56 miles by 37.1 miles) and is centered at 24 degrees south latitude, 132.7 degrees east longitude. North is toward the upper right. The colors are assigned to different radar frequencies and polarizations of the radar as follows: red is L-band, horizontally transmitted and received; green is C-band, horizontally transmitted, vertically received; and blue is the ratio of C-band to L-band, both horizontally transmitted and received. SIR-C/X-SAR, a joint mission of the German, Italian and United States space agencies, is part of NASA's Mission to Planet Earth program.

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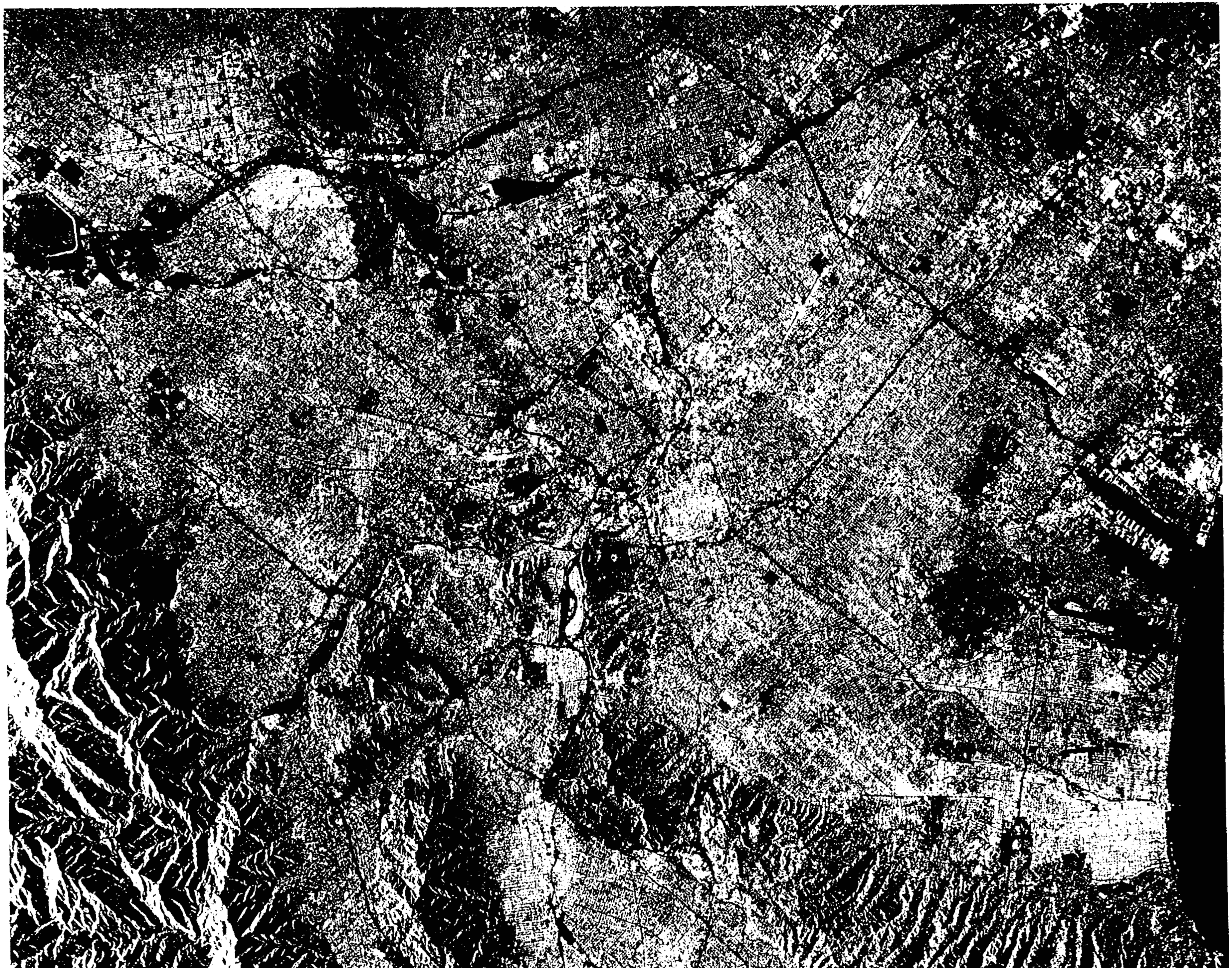

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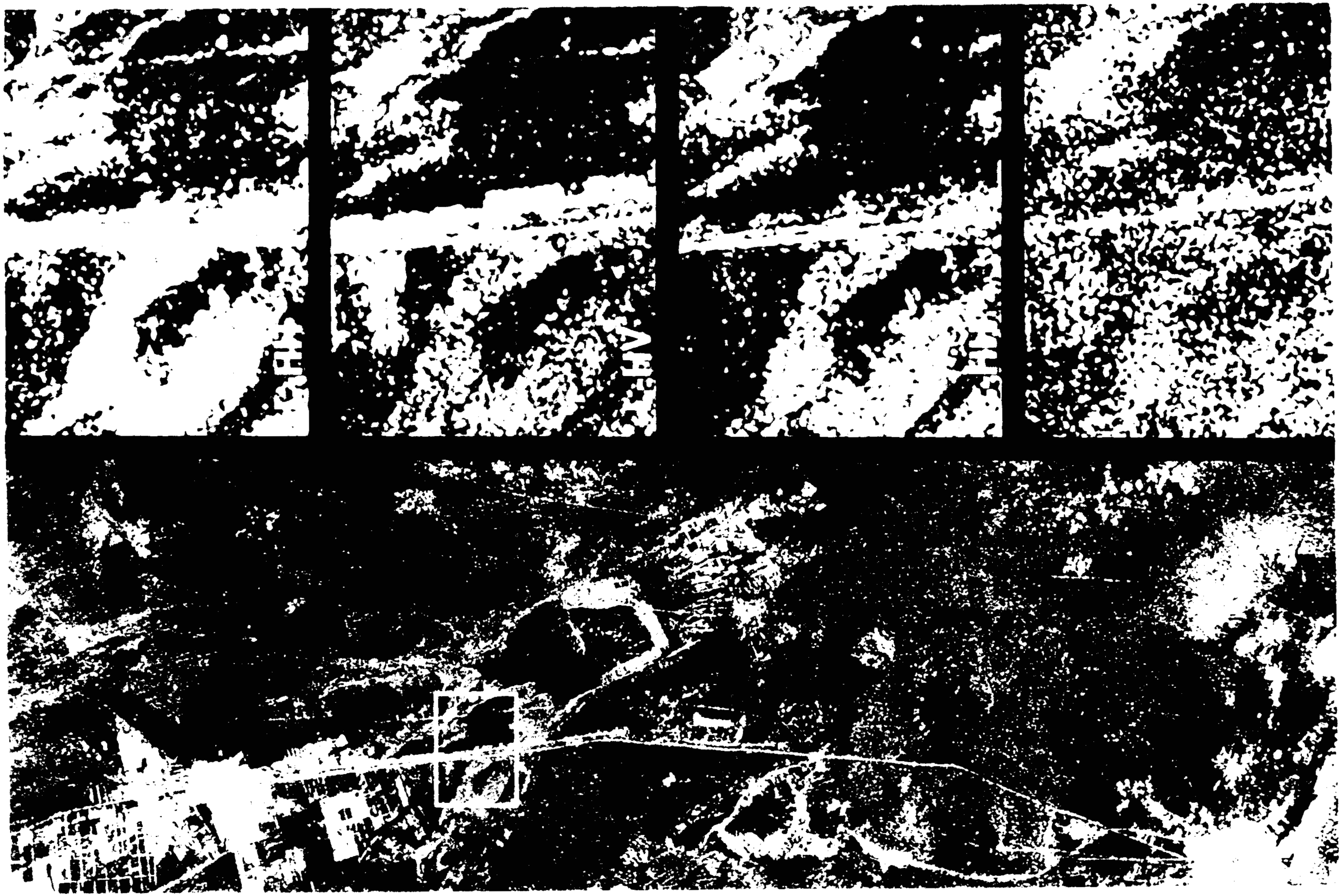
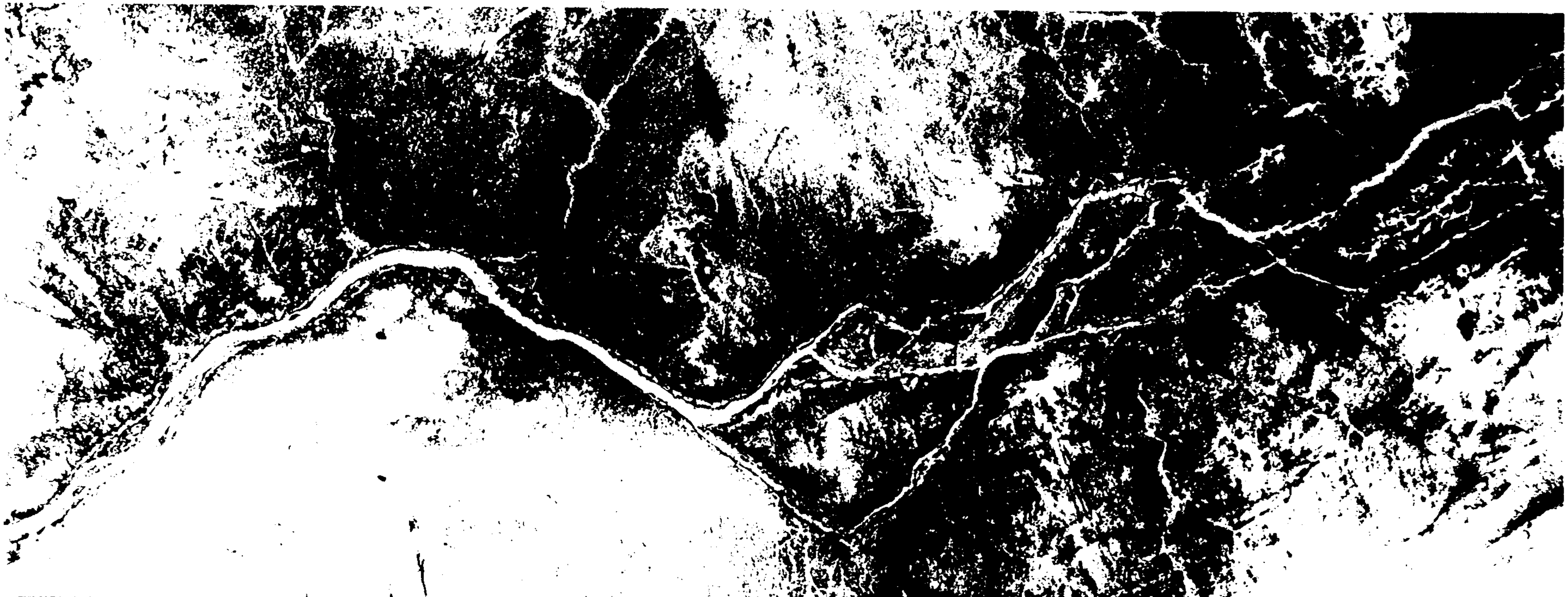
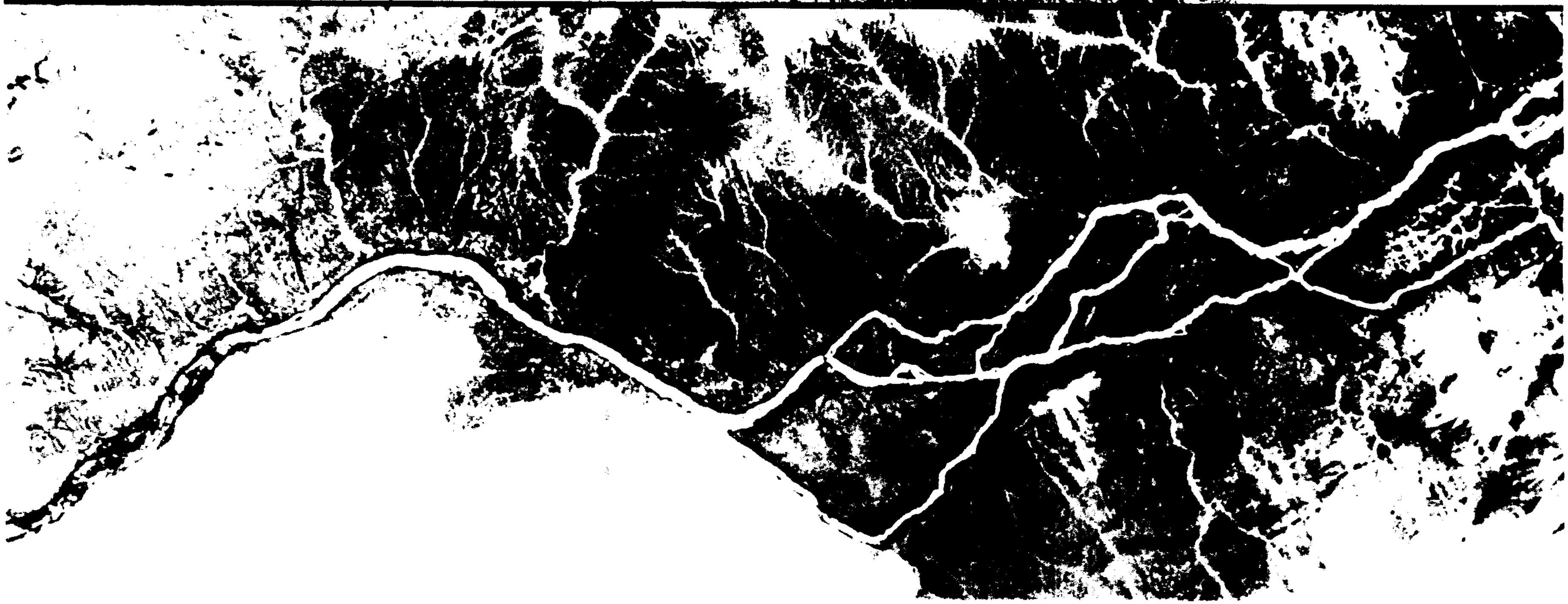
PHOTO CAPTION

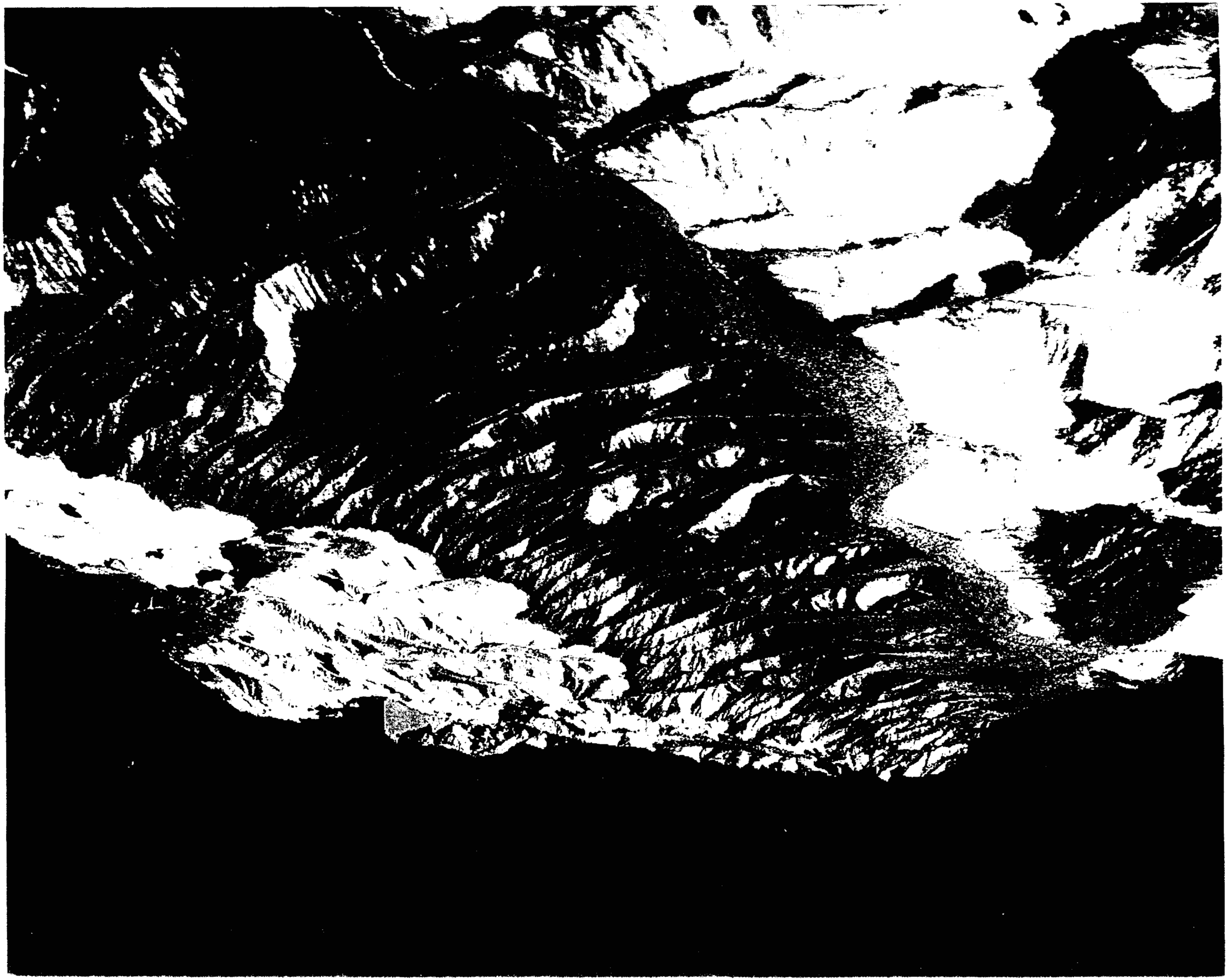
P-45861
July 20, 1995
Los Angeles, California

This radar image shows the massive urbanization of Los Angeles, California. The image extends from the Santa Monica Bay at the left to the San Gabriel Mountains at the right. Downtown Los Angeles is in the center of the image. The runways of the Los Angeles International Airport appear as black strips at the left center of the image. The waterways of Marina del Rey are seen just above the airport. The San Gabriel Mountains and the city of Pasadena are at the right center of the image. Black areas on the mountains on the right are fire scars from the 1993 Altadena fire. The Rose Bowl is shown as a small circle near the right center. The complex freeway system is visible as dark lines throughout the image. Some city areas, such as Santa Monica in the upper left, appear red due to the alignment of streets and buildings to the incoming radar beam. The image was acquired by the Spaceborne Imaging Radar-C/X-band Synthetic Aperture Radar (SIR-C/X-SAR) onboard the space shuttle Endeavour on October 3, 1994. SIR-C/X-SAR, a joint mission of the German, Italian and the United States space agencies, is part of NASA's Mission to Planet Earth. This image is centered at 34.04 degrees North latitude and 118.2 degrees West longitude with North pointing toward the upper right. The area shown measures 40 kilometers by 50 kilometers (25 miles by 31 miles).









Young's Interferometer

- In Young's experiment, a point source illuminates two separated vertical slits in an opaque screen. The slits are very narrow and act as line sources. For this case, the pattern of intensity variations on the observing screen is bright/dark banding.

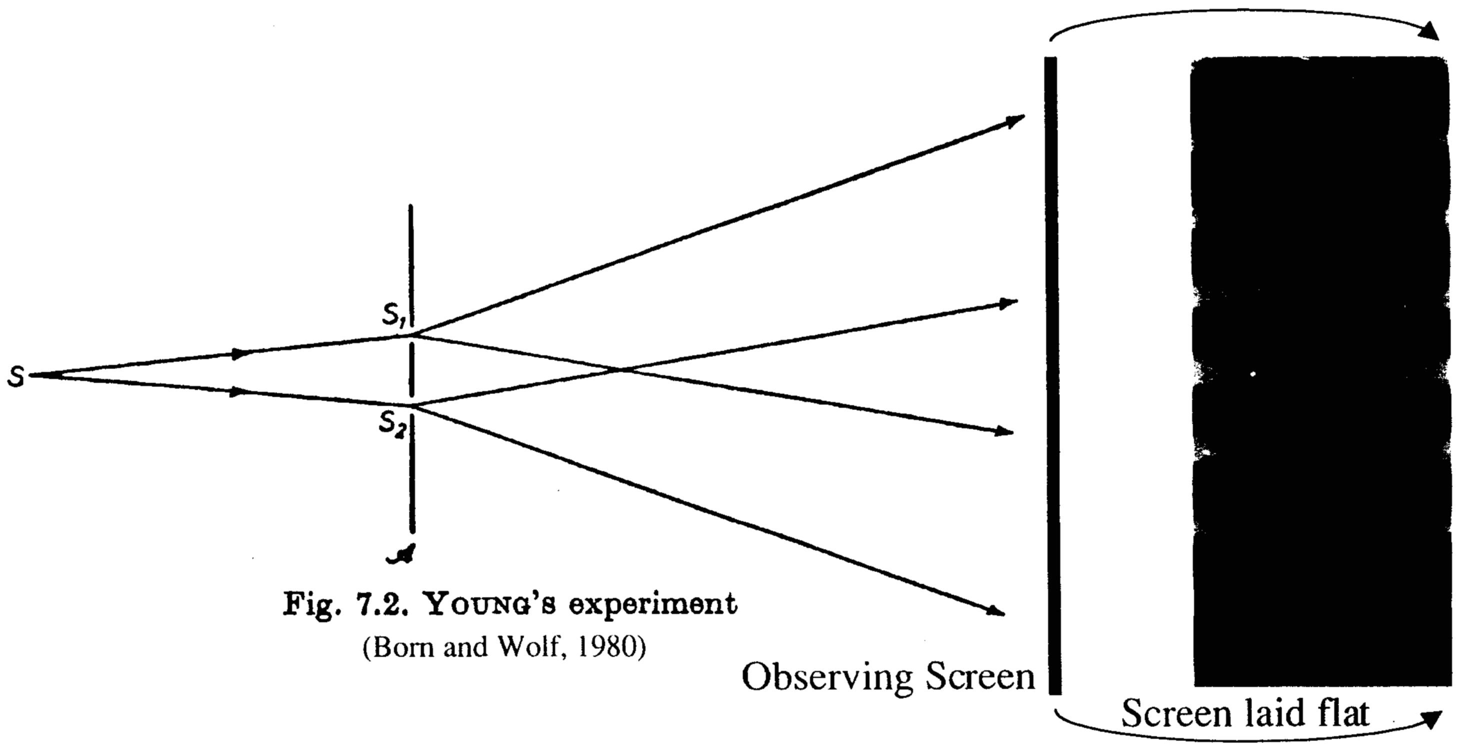
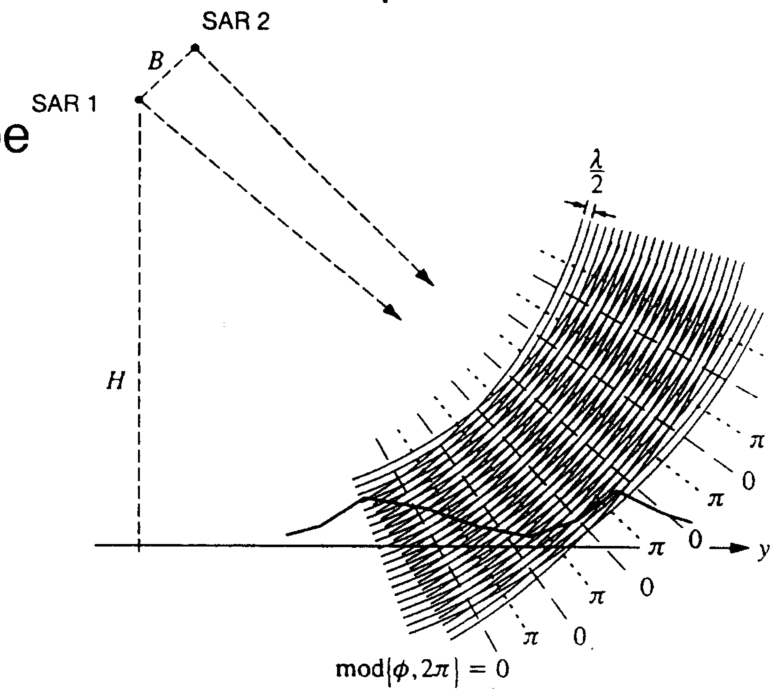


Fig. 7.2. YOUNG's experiment
(Born and Wolf, 1980)

Radar Interferometry

- Radar Interferometry is a simple extension of the Young's interferometry concept
- Radar has a coherent source much like a laser
- The two radar (SAR) antennas act as coherent point sources
- Because the wavelengths are so long, the signal can easily be digitized and processed coherently, measuring the phase information directly.
- When imaging a surface, the phase fronts from the two sources interfere.
- The surface topography slices the interference pattern.



- The measured phase differences record the topographic information.

Interferometry for Topography

Measured phase difference:

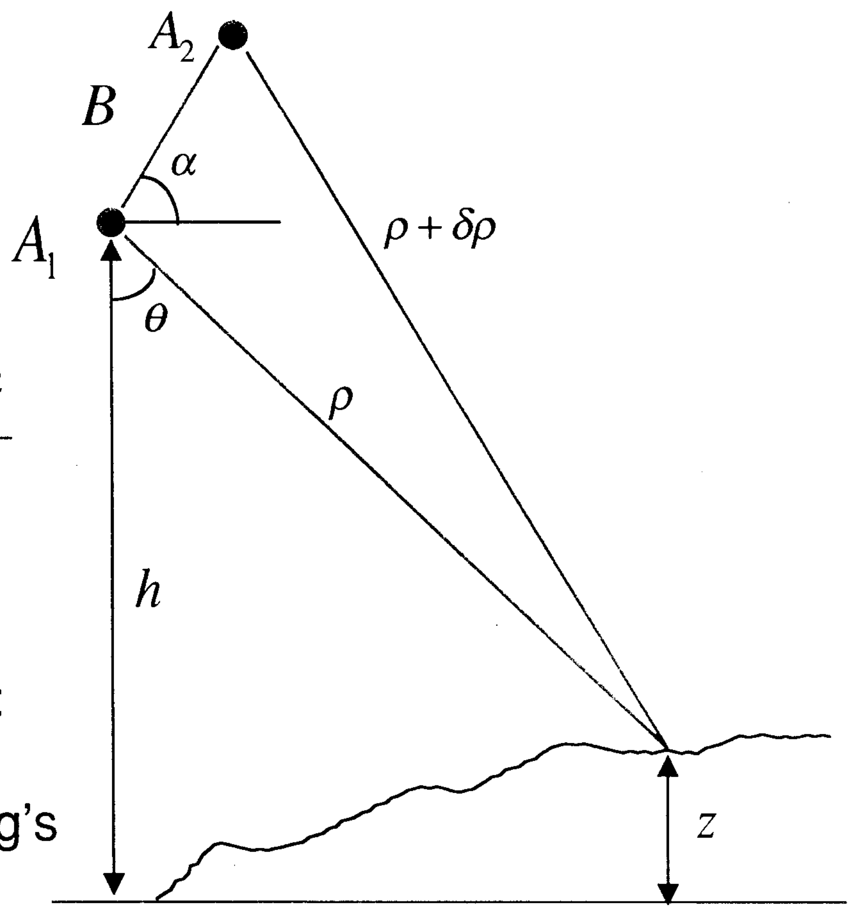
$$\phi = -\frac{2\pi}{\lambda}\delta\rho$$

Triangulation:

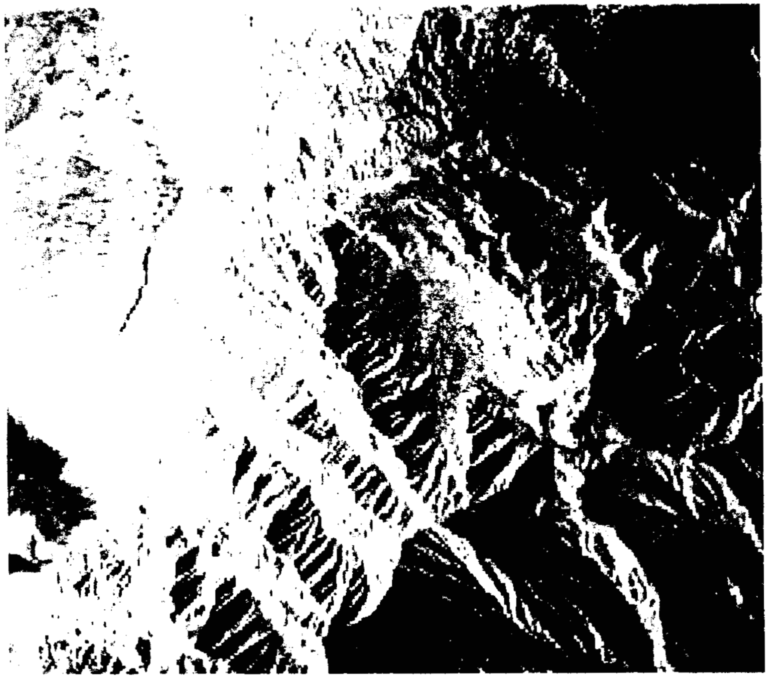
$$\sin(\theta - \alpha) = \frac{(\rho + \delta\rho)^2 - \rho^2 - B^2}{2\rho B}$$

$$z = h - \rho\cos\theta$$

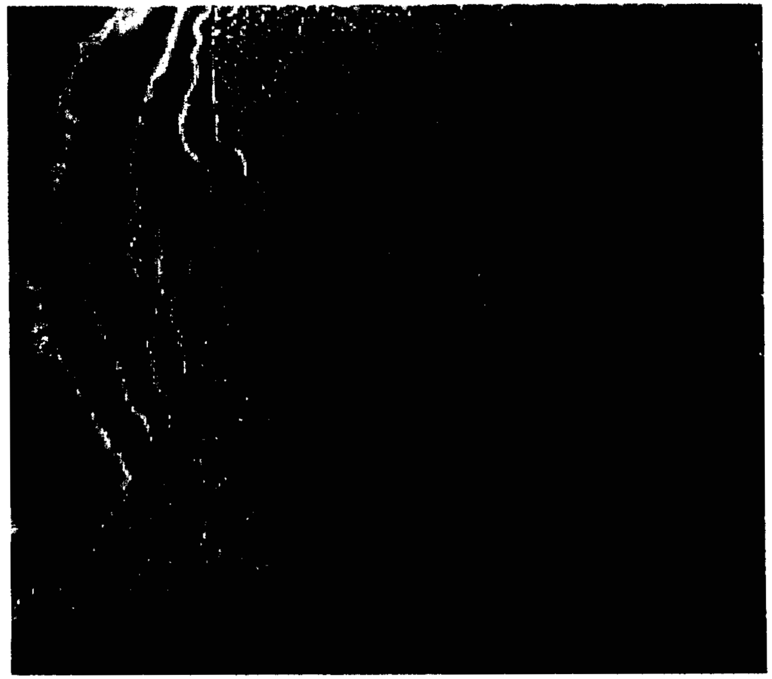
Critical Interferometer Knowledge:
- Baseline, (B, α), to mm's
- System phase differences, to deg's



Radar Interferometry Example



Standard Radar Image



Interference fringes follow the topography

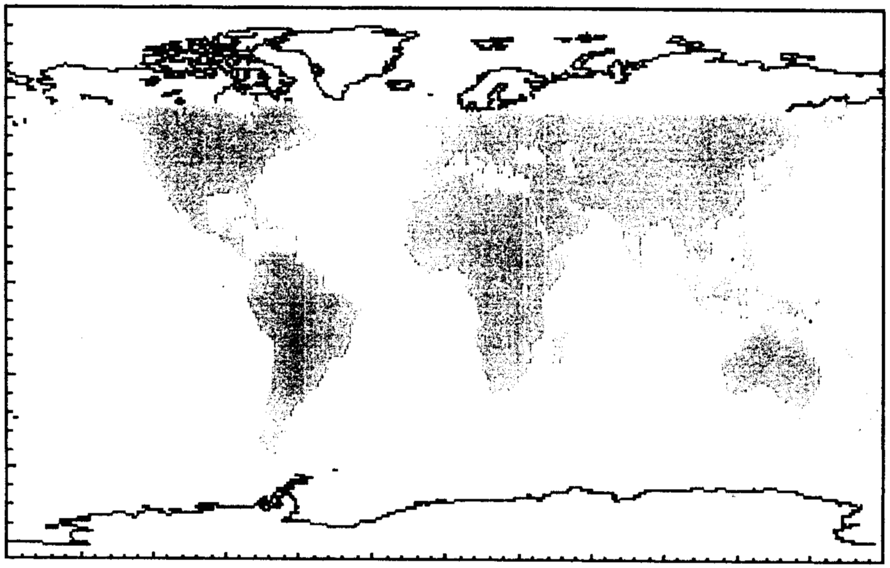
One cycle of color represents 1/2 wavelength of path difference

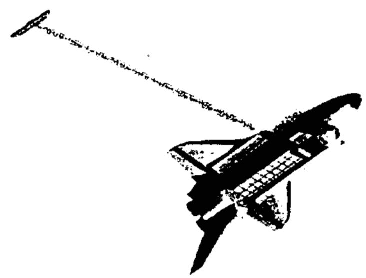
OBJECTIVES

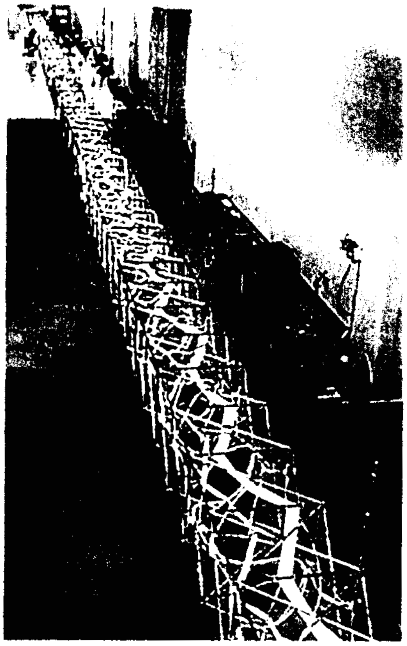
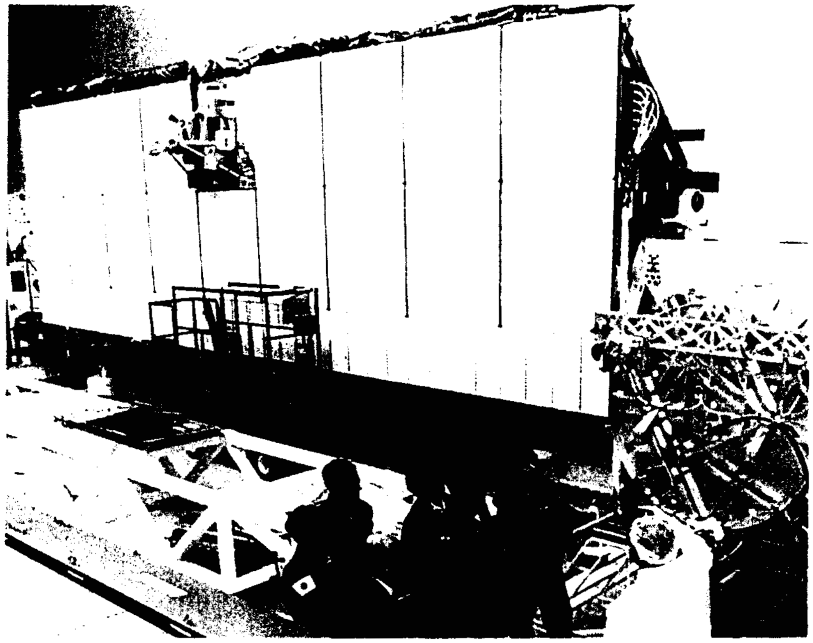
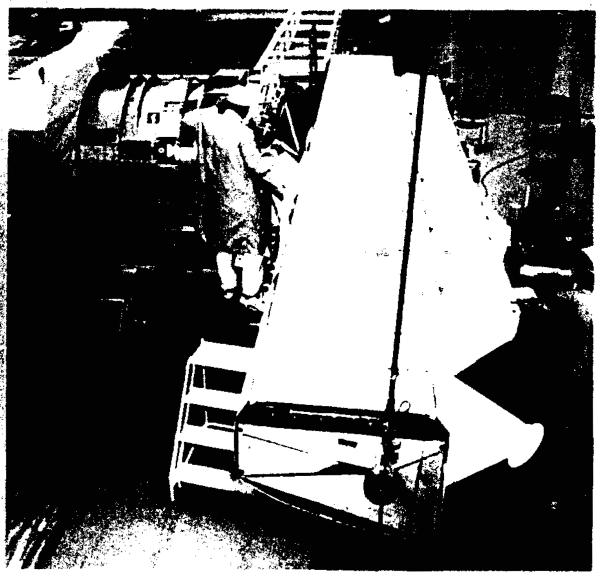
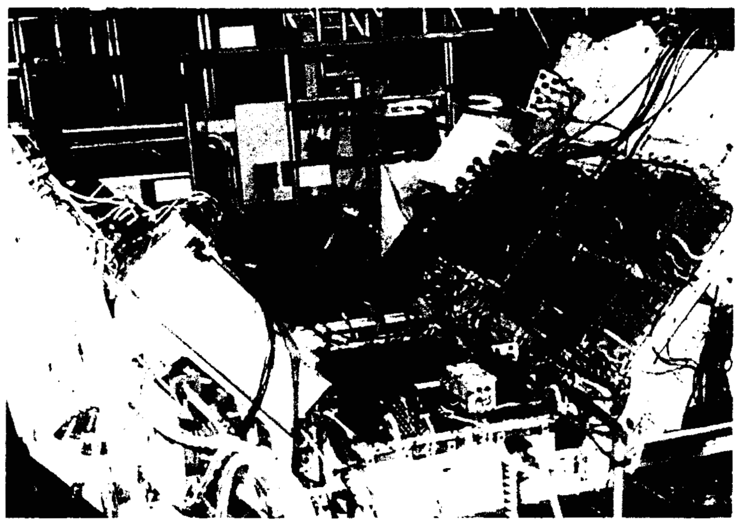
During a single 11-day Space Shuttle flight, SRTM will produce:

- **A digital topographic map of 80% of Earth's land surface with:**
  - **30 meter horizontal resolution**
  - **10 meter relative height error**
  - **Globally consistent characteristics and datum**

- **Rectified, terrain-corrected, C-band radar image mosaic**

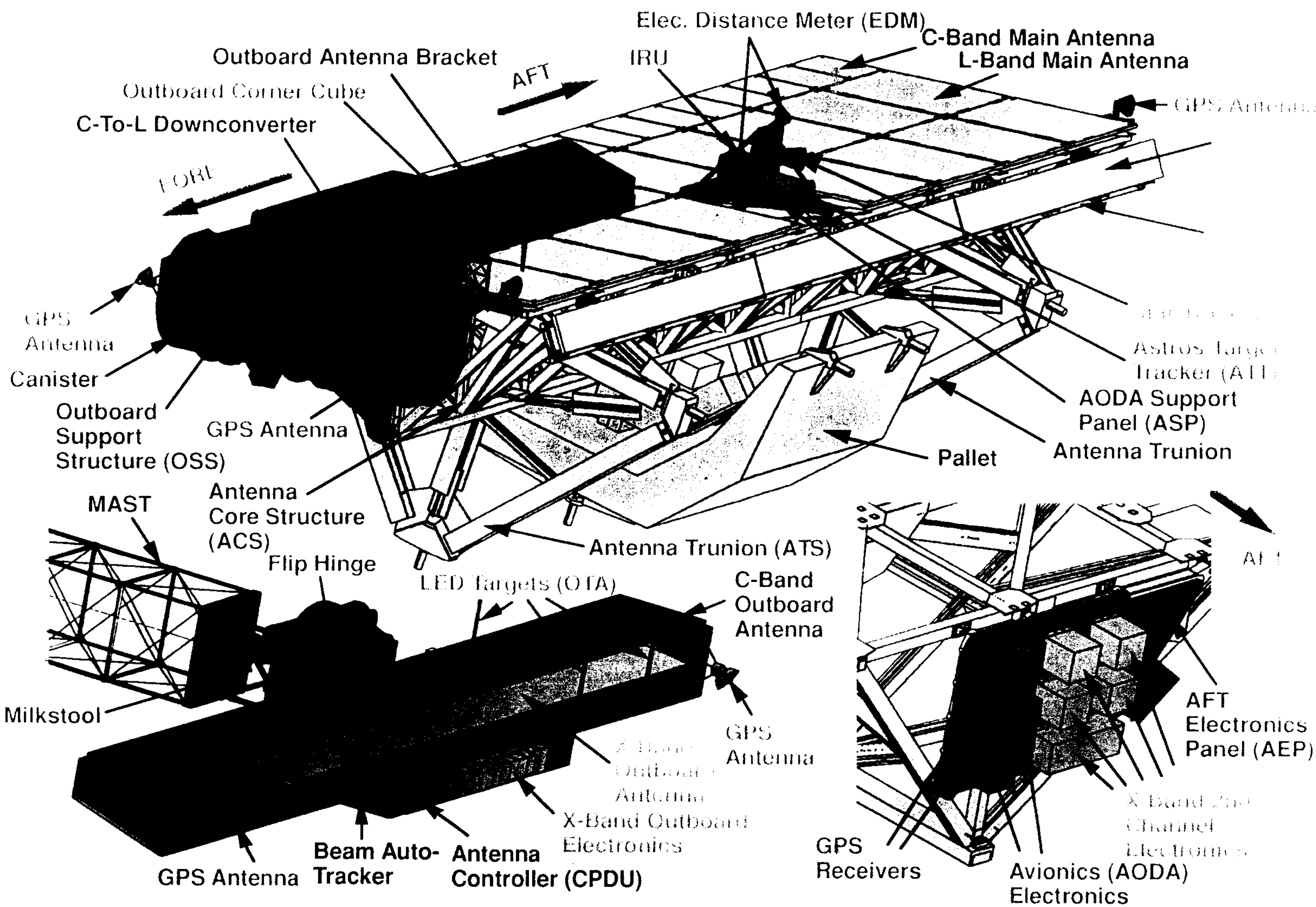


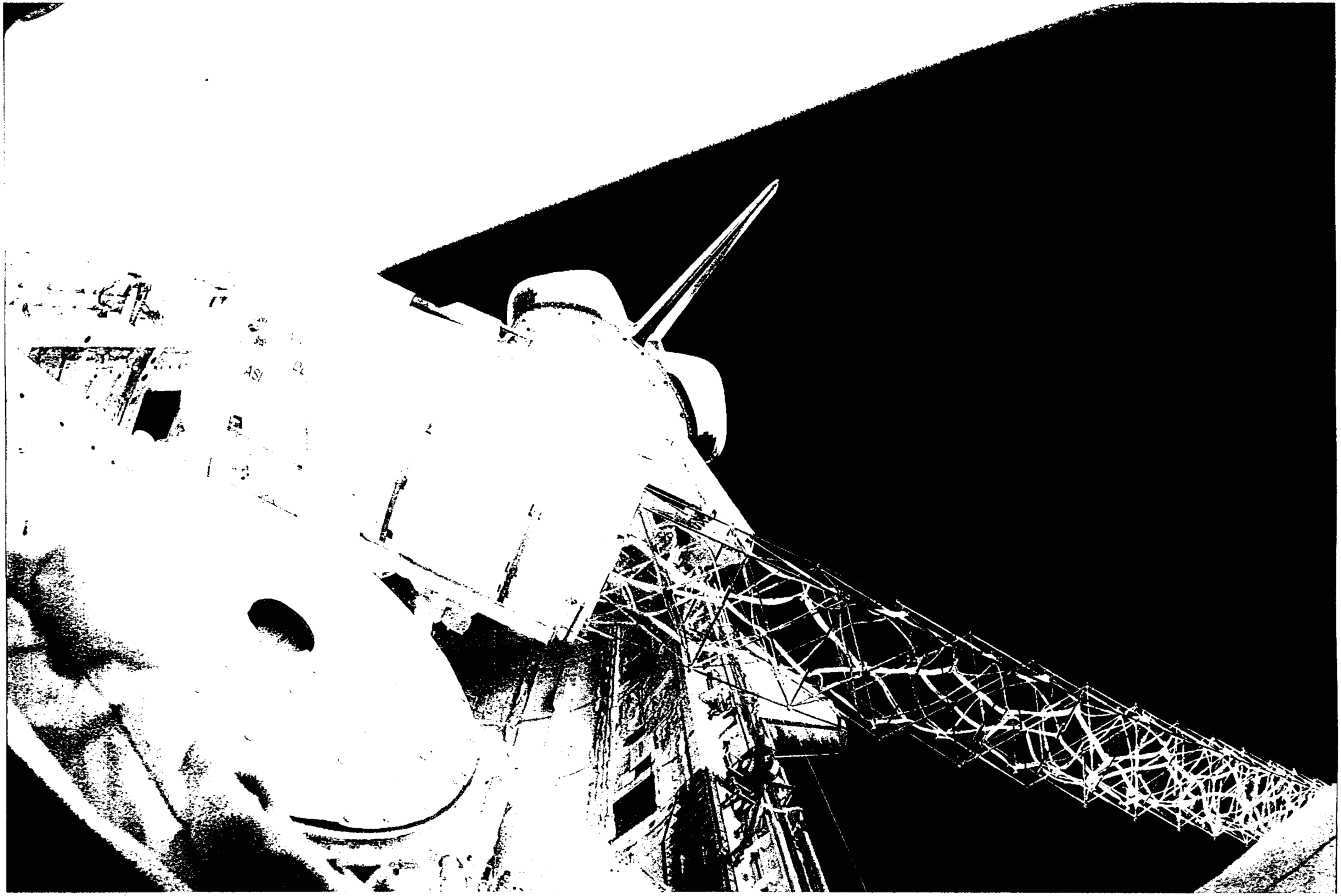


Shuttle Radar Topography Mission Equipment: Clockwise from upper left: Fully extended sixty meter mast; Inboard antenna with attitude sensors and canister (STS 99 crew in foreground); Radar electronics on shuttle pallet; Outboard antenna with mast stowed in canister.

SRTM Payload Configuration





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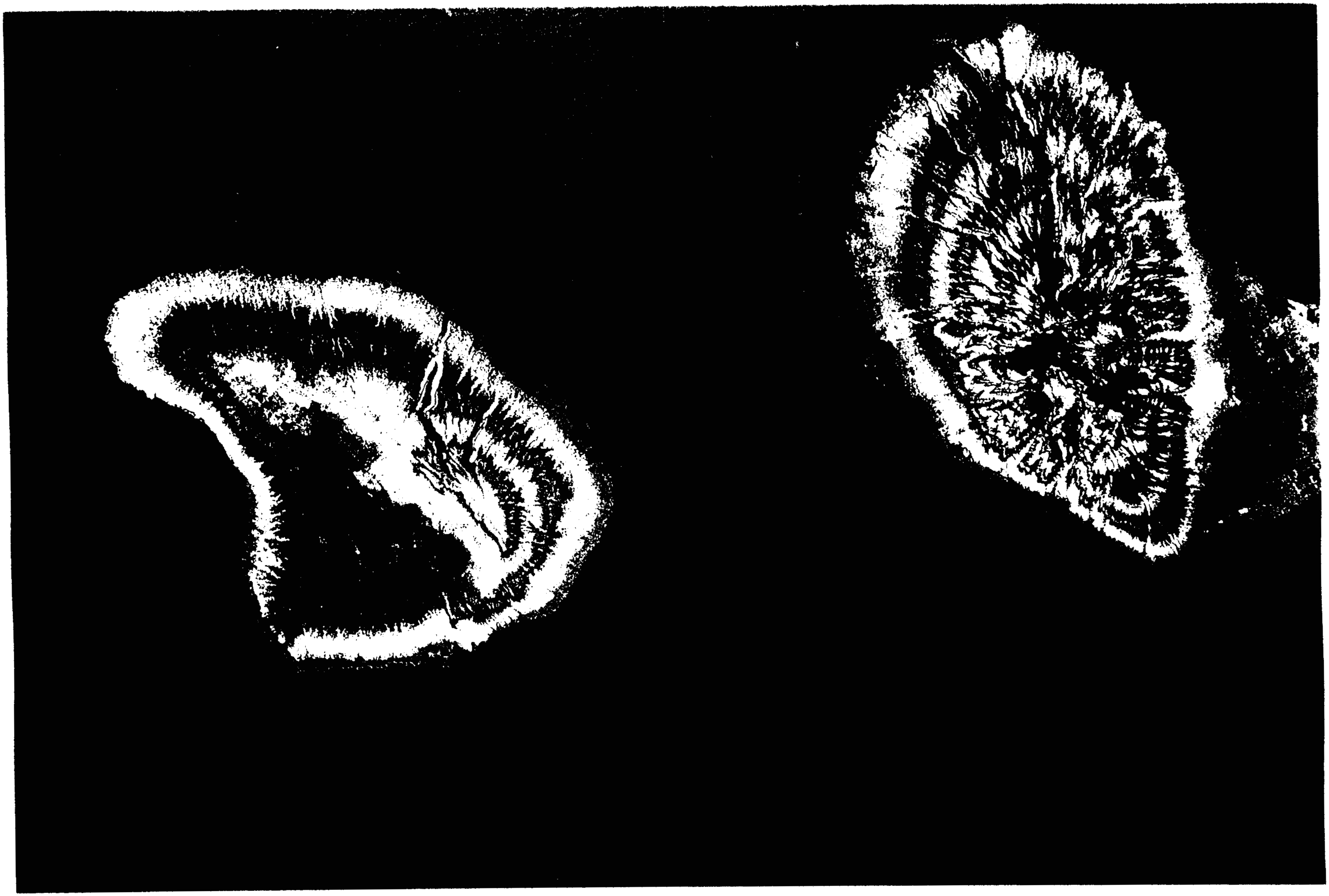
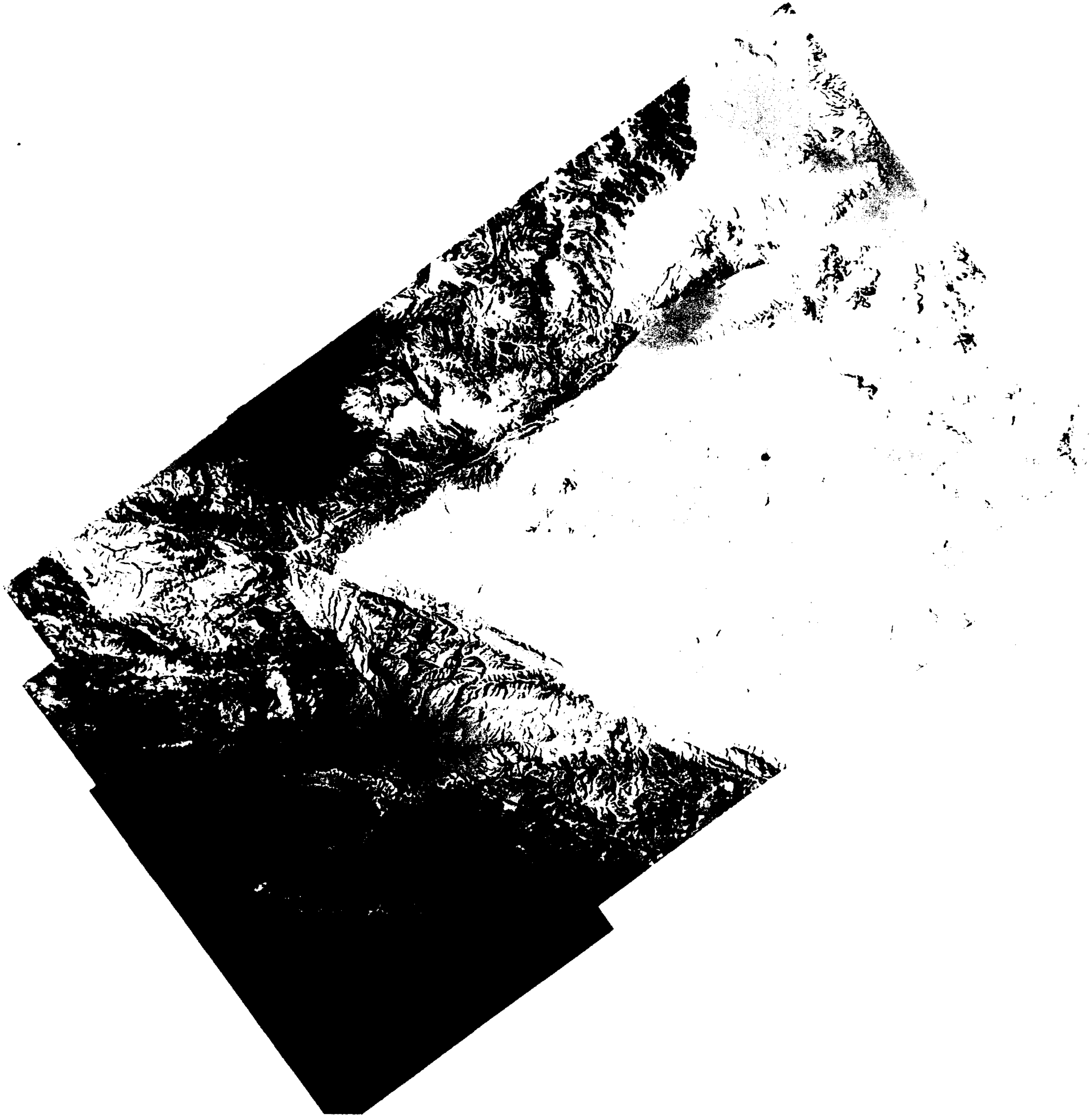
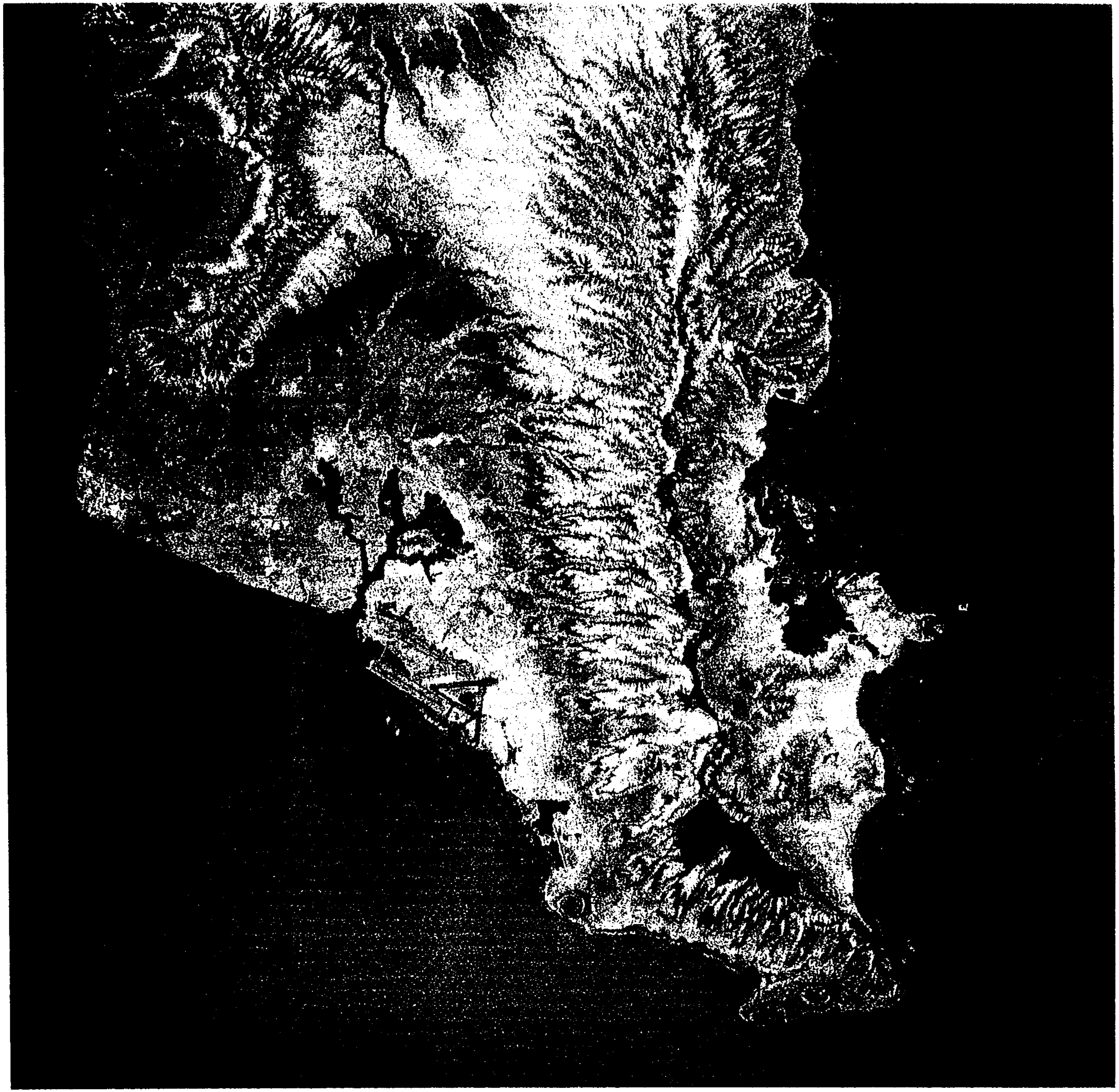
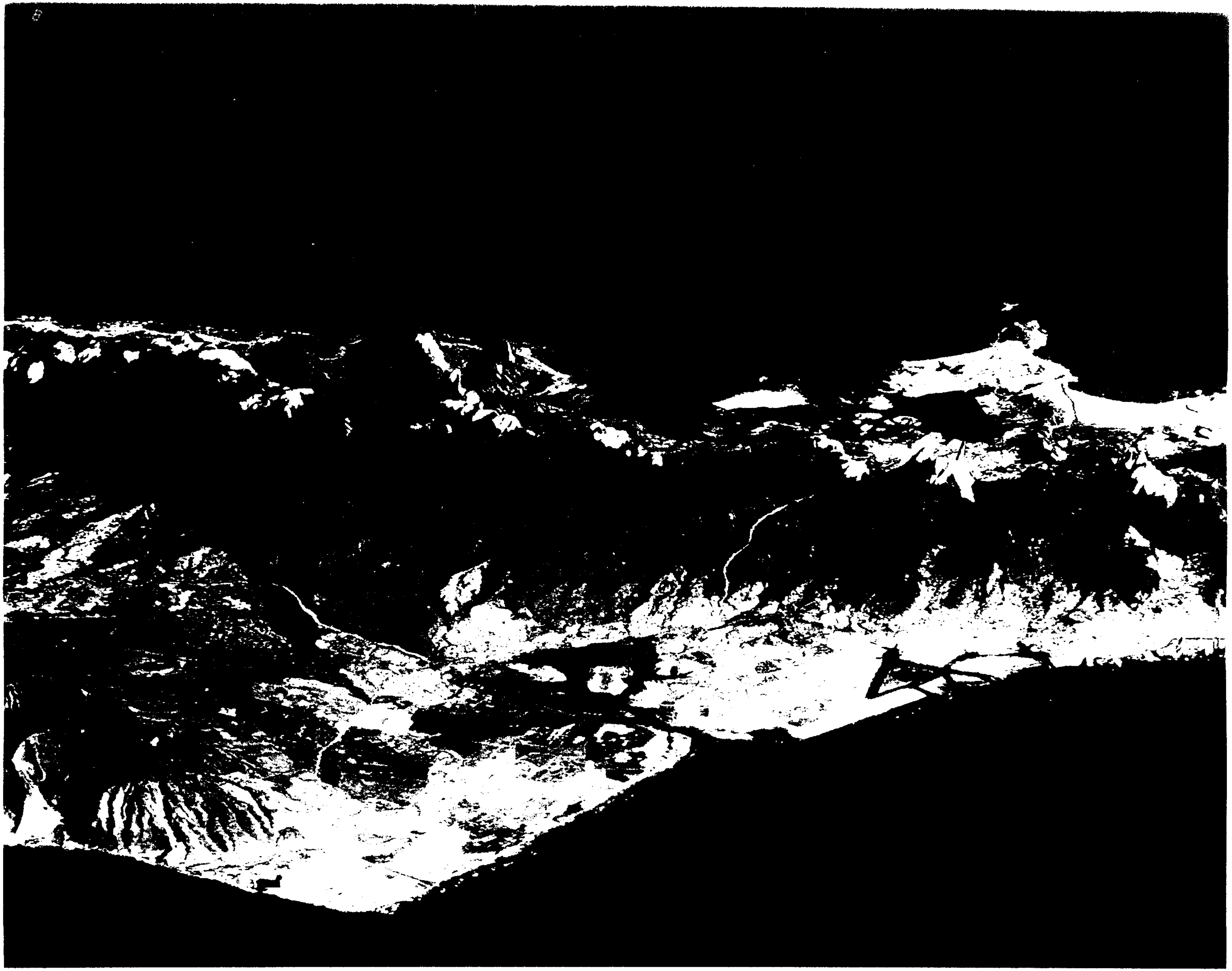
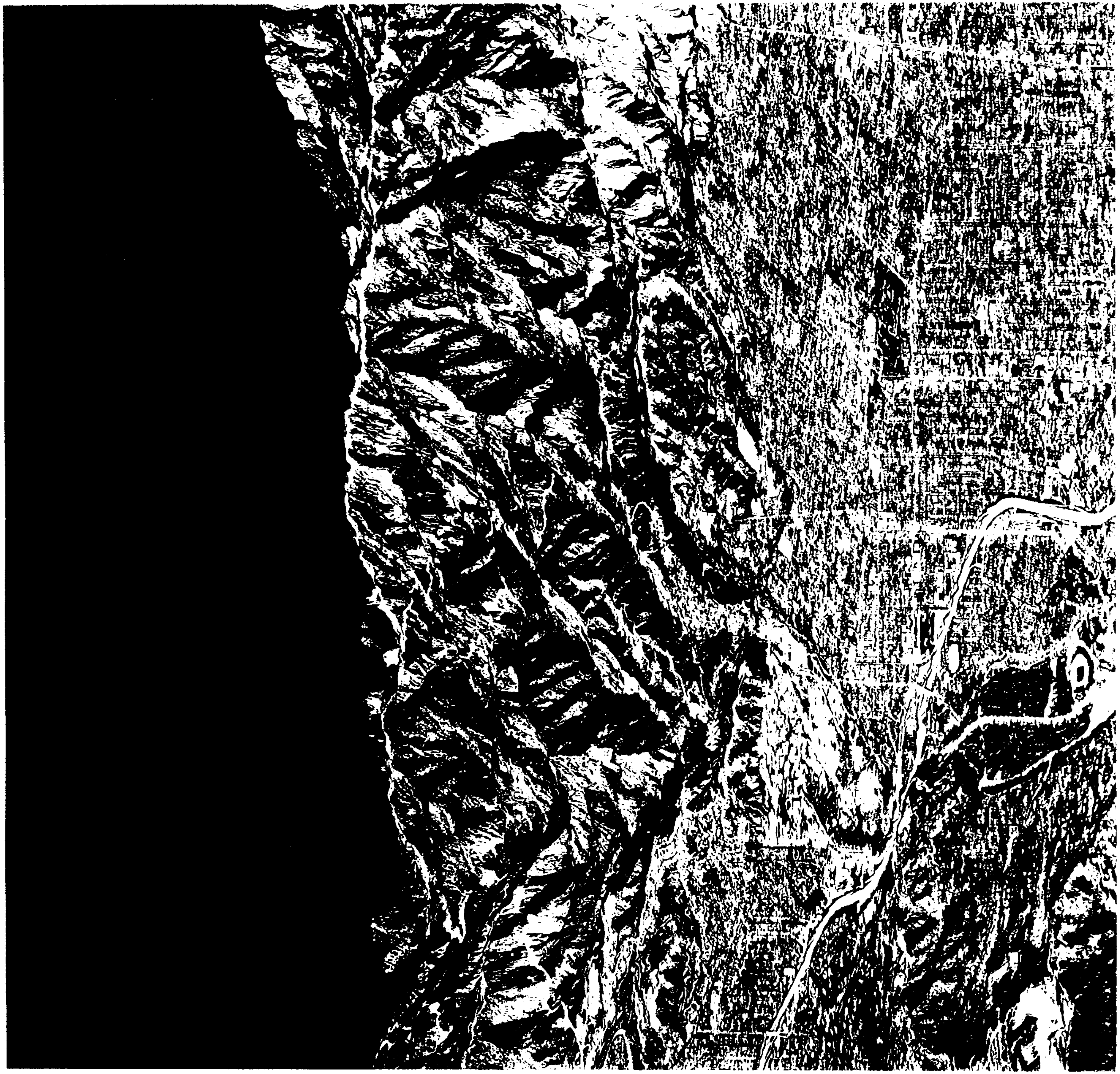
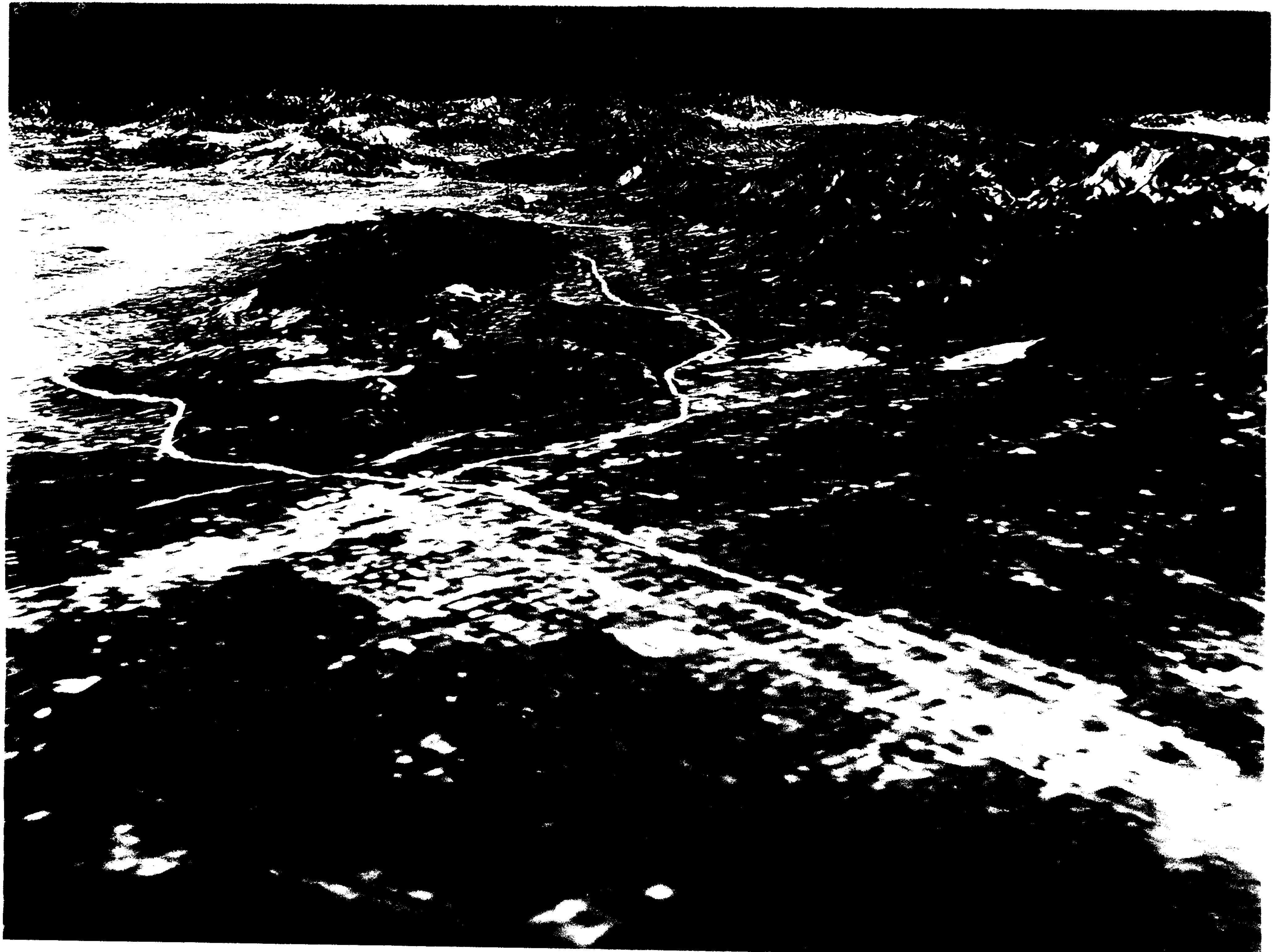










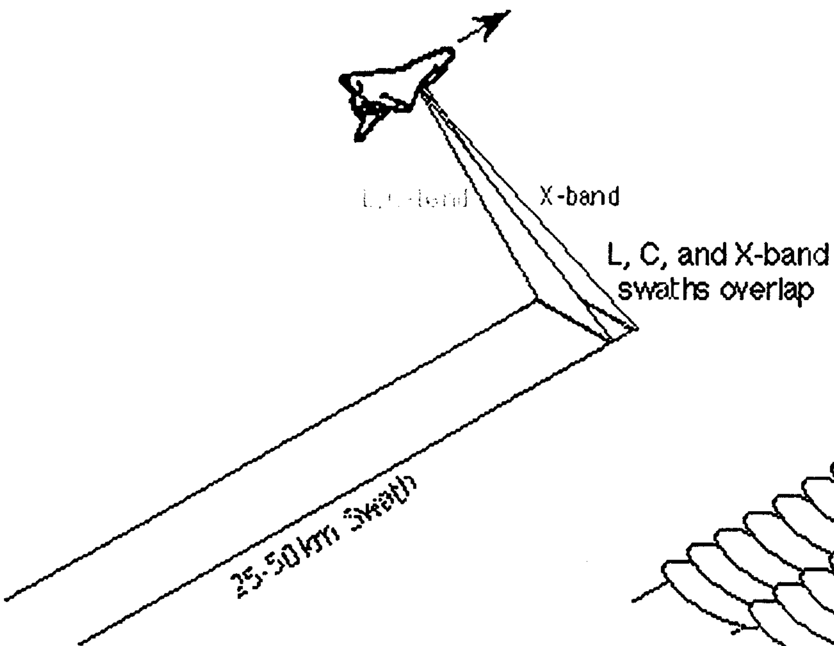


JPL

Shuttle Radar Topography Mission

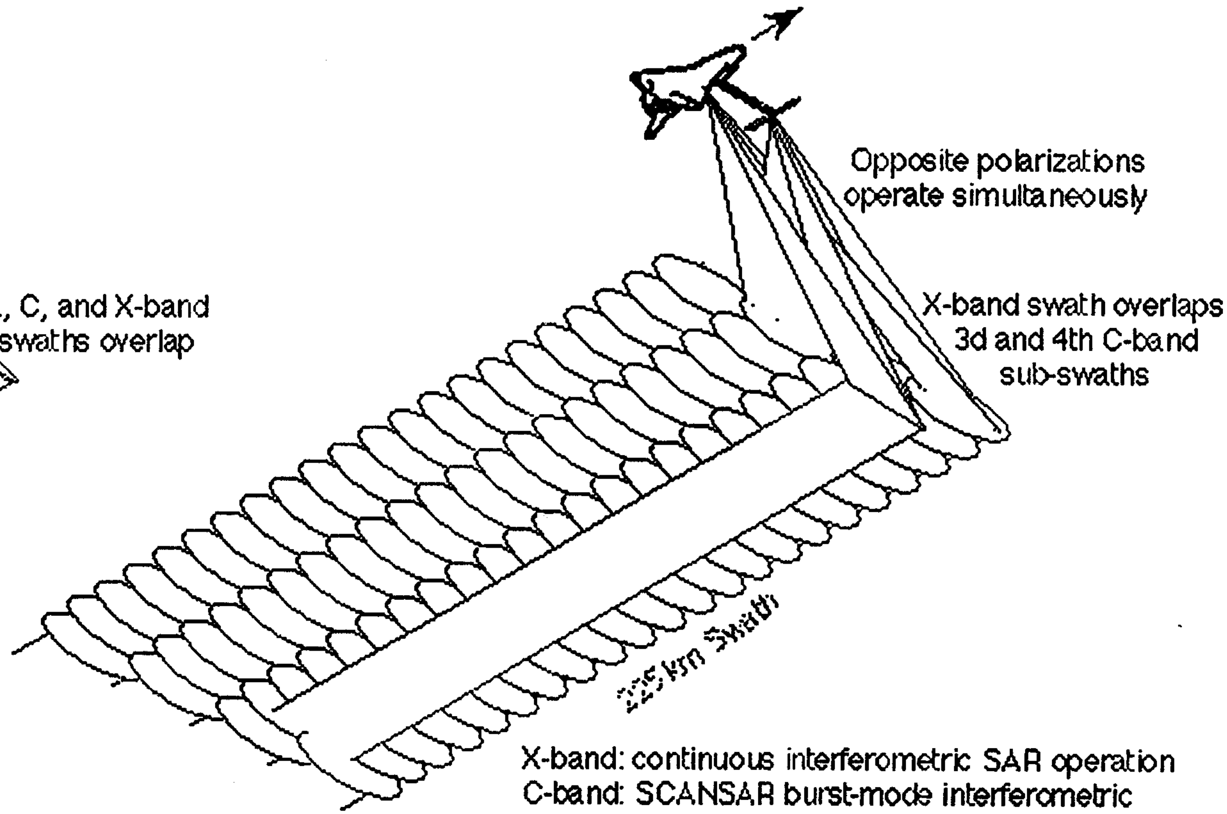
Operations Concepts

SRL



L, C, and X-band: continuous SAR operation

SRTM



X-band: continuous interferometric SAR operation
C-band: SCANSAR burst-mode interferometric operation with dual polarizations

AODA Functional Overview

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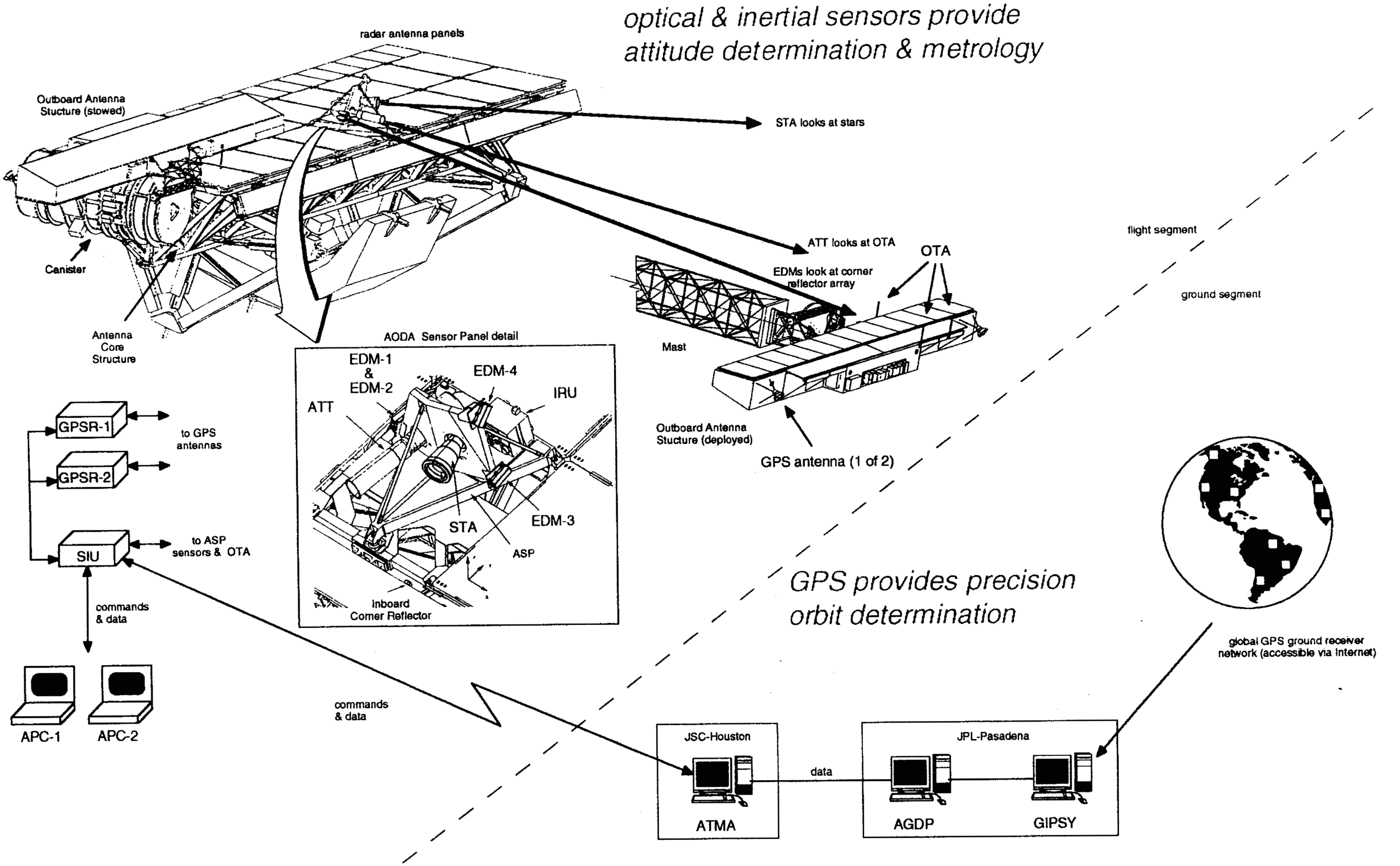
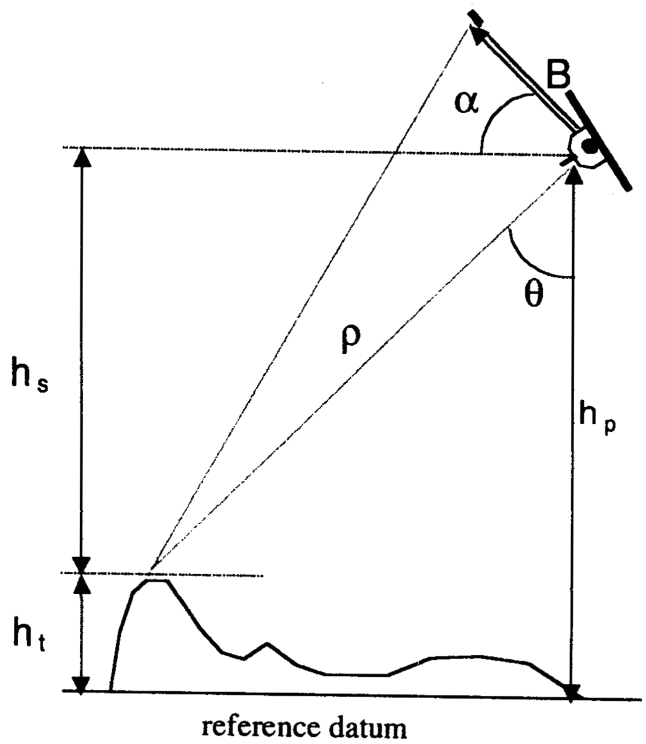
Jet Propulsion Laboratory
California Institute of Technology



AODA Key Knowledge Requirements (1.6 σ)

	Required	Observed	
Baseline roll angle (α)	9	3	arcsecs
Baseline length (B)	2	<2	mm
Platform position (h_p)	1	<1	m
Time-base	100	1	μs



Height reconstruction steps

1) use GPS to measure hp
2) use IFSAR (radar + metrology) to measure h_s
3) $h_t = h_p - h_s$

$h_s = \rho\cos(\arcsin(\lambda\phi/2\pi B)+\alpha)$

Where

B = baseline length

α = baseline roll angle

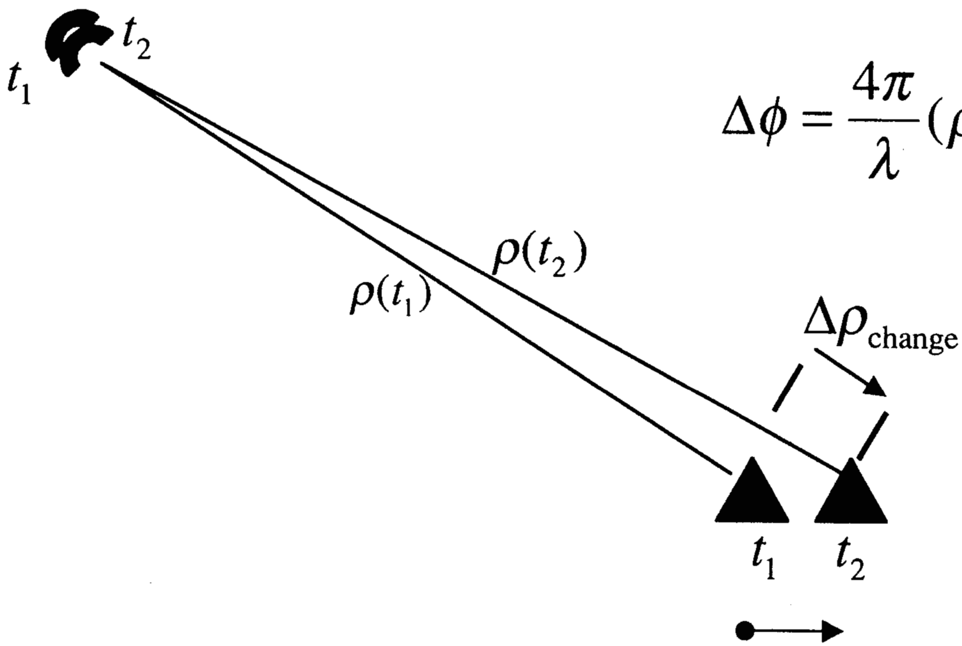
ϕ = phase shift

ρ = slant range

λ = wavelength

Differential Interferometry

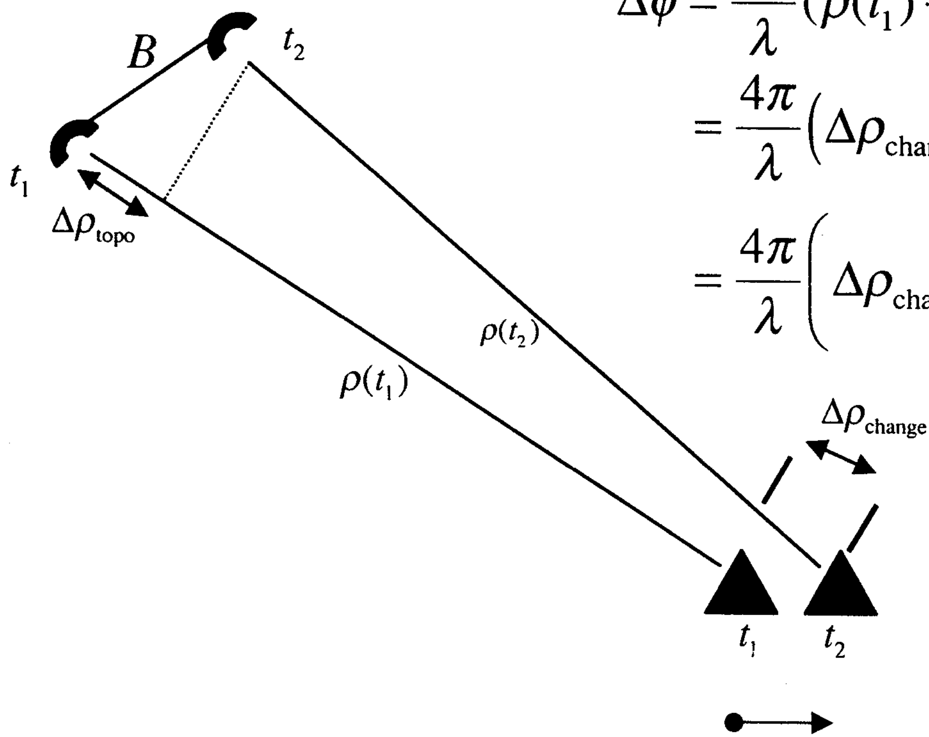
When two observations are made from the same location in space but at different times, the interferometric phase is proportional to any change in the range of a surface feature directly.



$$\Delta\phi = \frac{4\pi}{\lambda}(\rho(t_1) - \rho(t_2)) = \frac{4\pi}{\lambda}\Delta\rho_{\text{change}}$$

Differential Interferometry and Topography

Generally two observations are made from different locations in space and at different times, so the interferometric phase is proportional to topography and topographic change.



$$\Delta\phi = \frac{4\pi}{\lambda}(\rho(t_1)-\rho(t_2)) = \frac{4\pi}{\lambda}(\Delta\rho_{\text{change}} - \Delta\rho_{\text{topo}})$$

$$= \frac{4\pi}{\lambda}\left(\Delta\rho_{\text{change}} - B\sin(\theta-\alpha)\right)$$

$$= \frac{4\pi}{\lambda}\left(\Delta\rho_{\text{change}} - B\cos(\theta_0-\alpha)\frac{z}{\rho_0\sin\theta_0}\right)$$

If topography is known, then second term can be eliminated to reveal surface change

Surface Deformation Interferometry

Using three passes, for two interferometers to derive phases ϕ and ϕ' :

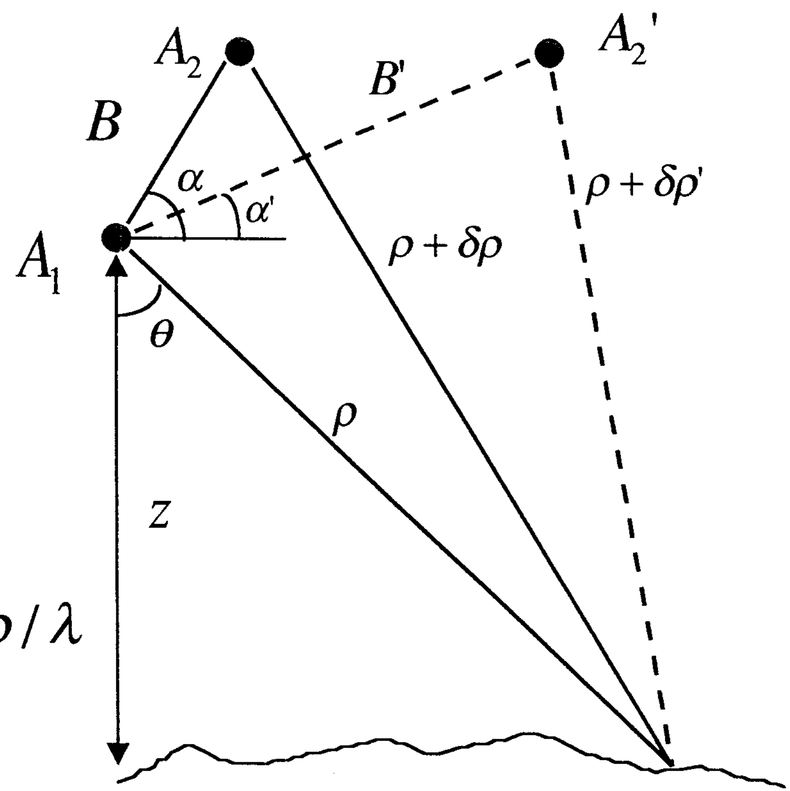
$$\phi = 4\pi B \sin(\theta - \alpha)/\lambda$$

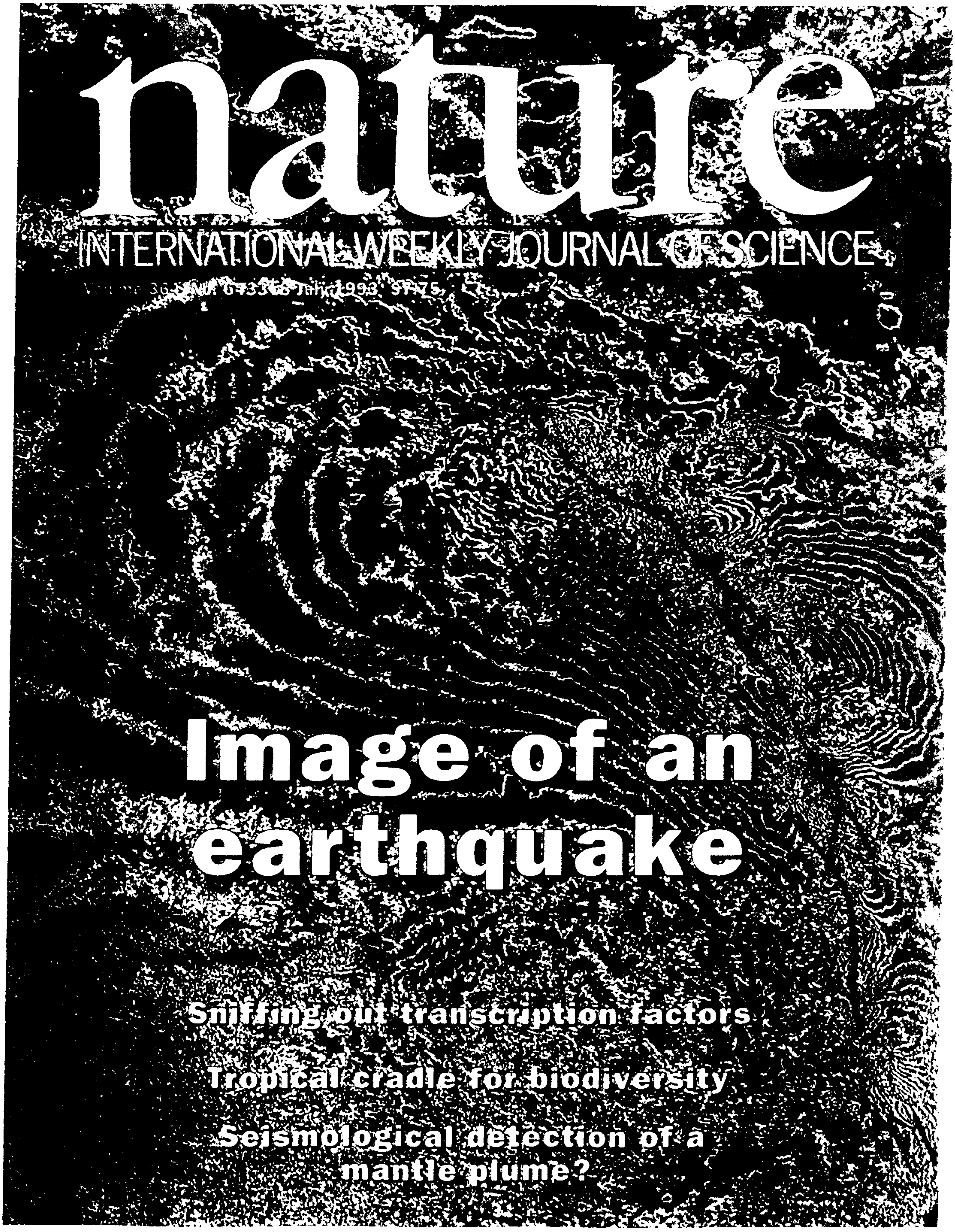
$$\phi' = 4\pi B' \sin(\theta - \alpha')/\lambda$$

If range changes by between observations, phase changes by $4\pi\Delta\rho/\lambda$

$$\phi' = 4\pi B' \sin(\theta - \alpha')/\lambda + 4\pi\Delta\rho/\lambda$$

To remove topographic phase, scale by baseline ratio and subtract




nature
INTERNATIONAL WEEKLY JOURNAL OF SCIENCE
Volume 36_ No. 6433 8 July 1993
Image of an earthquake
Sniffing out transcription factors
Tropical cradle for biodiversity
Seismological detection of a mantle plume?

Hector Mine Earthquake (Oct.16, 1999, Mw7.1)
ERS-2 data: Sep. 15 - Oct. 20, 1999
20 km
range
displacement
10 cm
ERS data: European Space Agency
Processing: GP, JPL, Oct. 1999
-116.75
-115.50

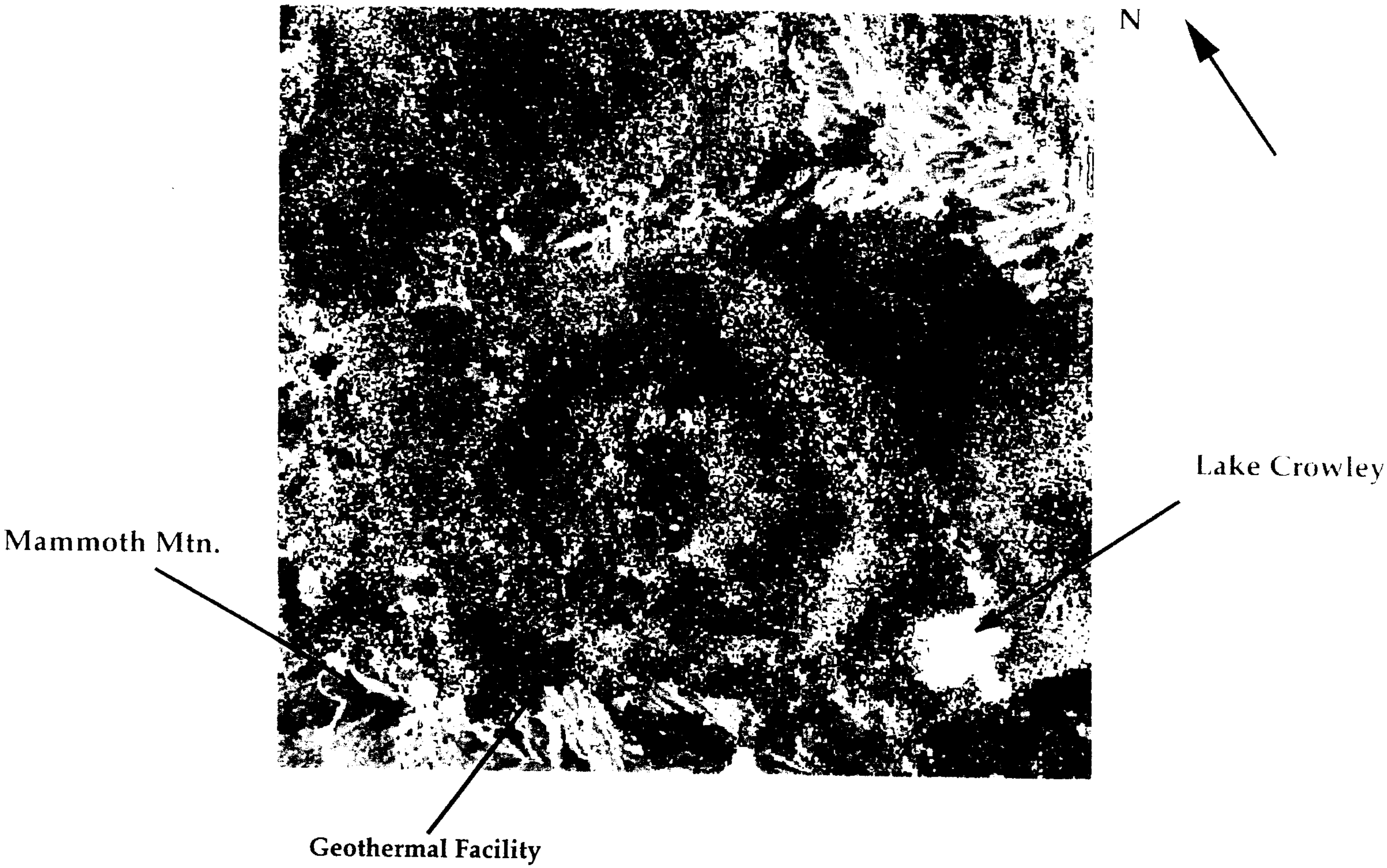
The image is an interferometric map of the Hector Mine earthquake area showing the ground displacement along the radar line of sight. One full color cycle represents 10 cm of range displacement. Gray areas are zones of low phase coherence that have been masked before unwrapping. Dotted lines depict California faults, after Jennings (1975), and thick, solid lines the Landers , 1992 surface rupture, after Sieh et al. (1993). Thin, solid lines within zone of dense fringes are surface breaks inferred from azimuth and range disparities (offsets) between before and after images, and phase discontinuities.

The topographic phase has been removed using a combination of the USGS 30 m and 90 m digital elevation maps. The rapid orbits from the ESA D-PAF were used to determine the interferometric baseline and to flatten the map. A small phase ramp was removed manually to minimize the far field displacement. Processing from RAW data to interferogram and geocoded map was done using the JPL/Caltech ROI_PAC software package.

The radar data were acquired by the European Space Agency ERS-2 satellite on September 15 and October 20, 1999. The data used here cover frames 2907 and 2925 of descending track 127. The post-earthquake data were purchased from Eurimage and transfered from the Centre Canadien de Teledetection to JPL via FTP.

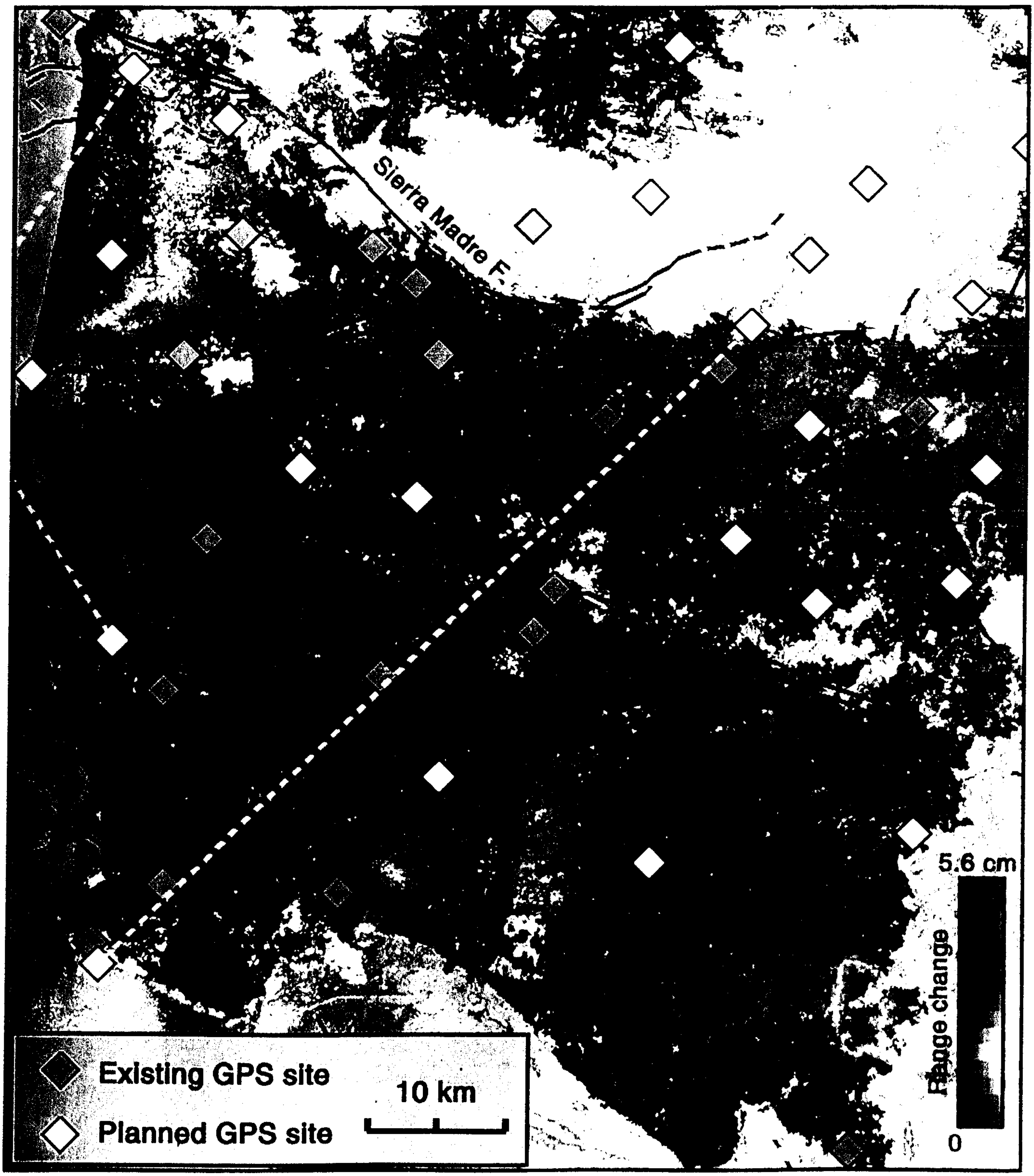
Interferometric SAR Image of Deformation at Long Valley Caldera, California

from ERS-1 observations
1992.6.17 - 1995.11.5



M. Simons, P. Rosen, F. Webb, 1997 JPL

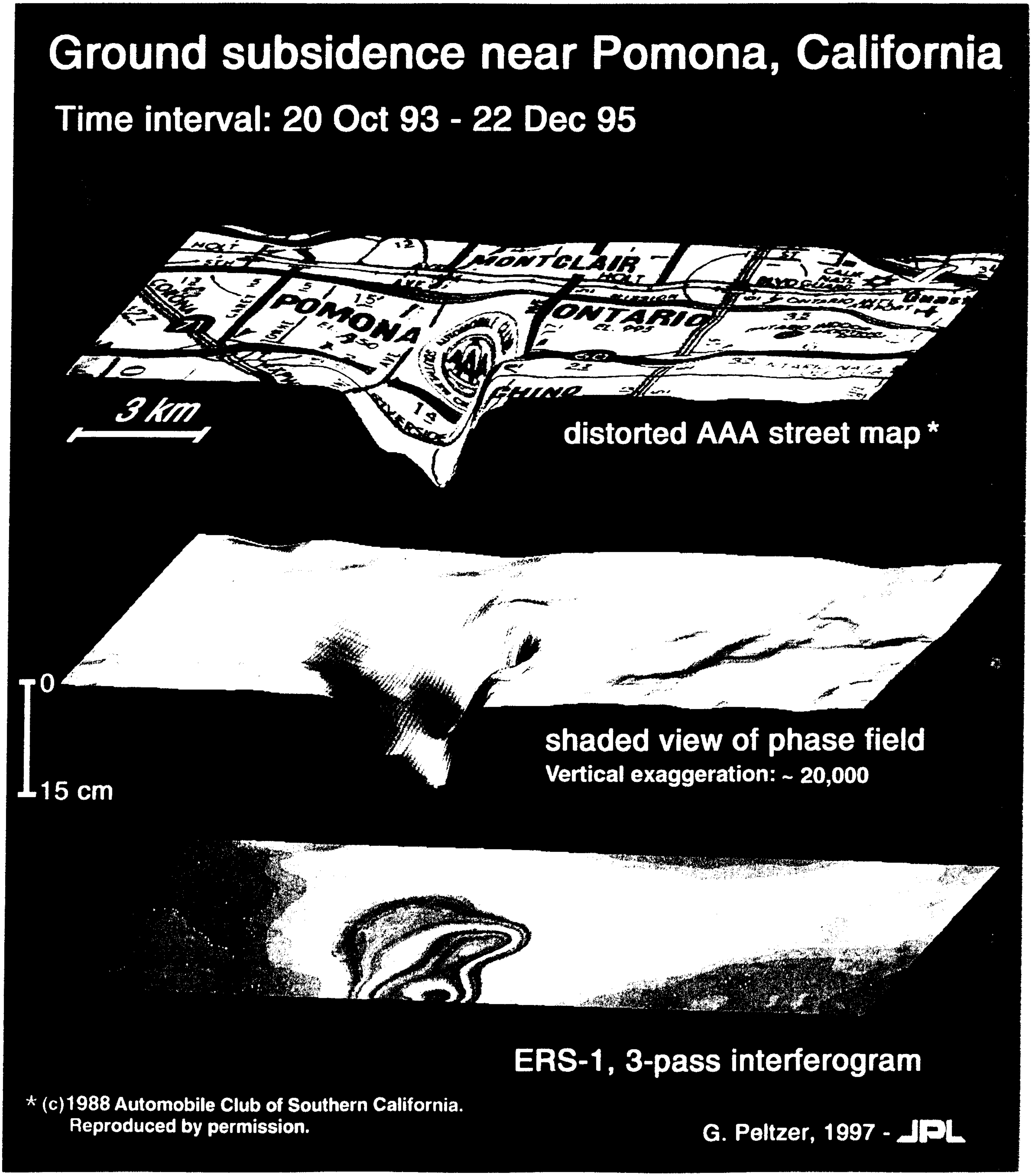
SAR INTERFEROMETRIC MAP OF LOS ANGELES AND SCIGN STATIONS

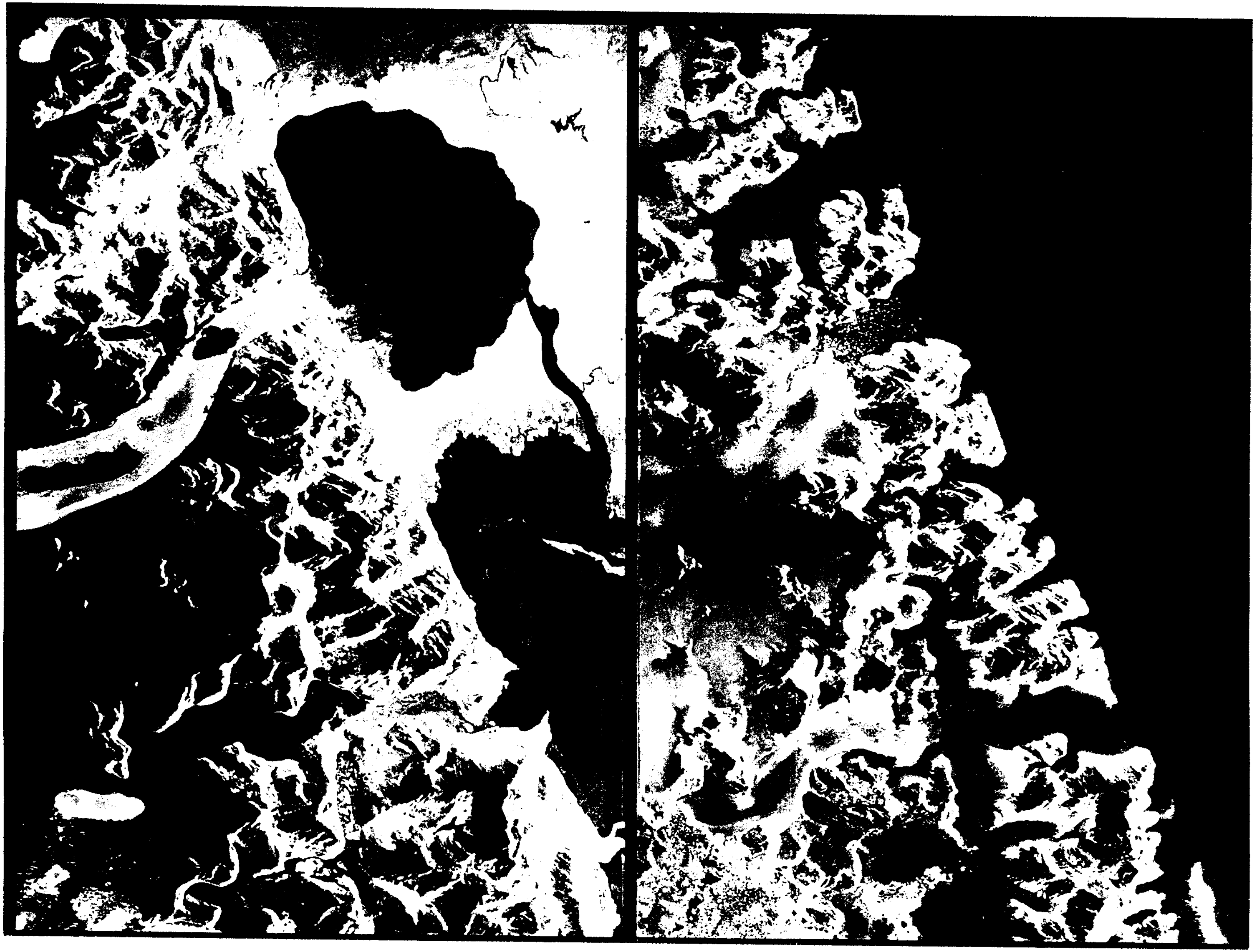


ERS radar data: ESA

G. Peltzer, 1996 - JPL

The image shows a surface displacement map of the Los Angeles area generated by interferometric processing of Synthetic Aperture Radar (SAR) data. Diamonds depict the location of existing and future GPS stations of the Southern California Integrated GPS Network (SCIGN). Black lines are mapped active faults. The colors of the radar image represent the change in range due to surface displacement toward the satellite antenna, which is illuminating the area from the east with an incidence angle of 23 deg. off the vertical. One full color cycle represents 5.6 cm of range change between the dates of acquisition of the radar data (20 October, 1993 - 22 December, 1995). Gray areas within the radar swath are zones where the radar correlation is lost due to steep slopes and seasonal change of the vegetation. Surface displacement in the Los Angeles region is primarily due to the tectonic activity. For example, the concentric rings visible along the western edge of the SAR swath is the result of the surface uplift produced by the M6.7 Northridge earthquake of January 17, 1994. Other features visible on the image are related to human activity such as water and oil withdrawal. Regions of ground subsidence include the Pomona (P) area (water), the Beverly Hills (BH) oil field (oil) and localized spots in the San Pedro and Long Beach airport (LBA) area (probably oil industry activity). Noticeable surface uplift is observed in Santa Fe Springs oil field (SFS) and east of Santa Ana (SA). Surface uplift in these areas may result from the recharge of aquifers or oil fields with water, or from the poro-elastic response of the ground subsequent to water or oil withdrawal. The combined analysis of SCIGN data and radar interferometric maps provides scientists with unprecedented temporally and spatially dense information about movements of the surface, bringing new insights into long term motion on faults and their seismic cycle, and into effects of human activity. The radar data were acquired by the European Space Agency ERS-1 satellite. The data processing was made at the Jet Propulsion Laboratory. The fault map is from the US Geological Survey.


Ground subsidence near Pomona, California
Time interval: 20 Oct 93 - 22 Dec 95
MONTCLAIR
HOLT
POMONA
ONTARIO
CHINO
3 km
distorted AAA street map *
0
15 cm
shaded view of phase field
Vertical exaggeration: ~ 20,000
ERS-1, 3-pass interferogram
* (c)1988 Automobile Club of Southern California.
Reproduced by permission.
G. Peltzer, 1997 - JPL



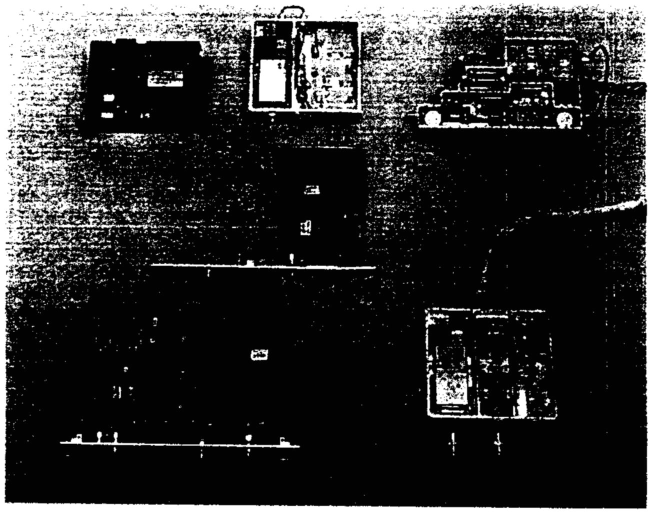
This image, produced with interferometric measurements made by the Spaceborne Imaging Radar-C and X-band Synthetic Aperture Radar (SIR-C/ X-SAR) flown on the Space Shuttle last fall, has provided the first detailed measurements of the mass and motion of the San Rafael Glacier. Very few measurements have been made of the Patagonian ice fields, which are the world's largest mid-latitude ice masses and account for more than 60 percent of the Southern Hemisphere's glacial area outside of Antarctica. These features make the area essential for climatologists attempting to understand the response of glaciers on a global scale to changes in climate, but the region's inaccessibility and inhospitable climate have made it nearly impossible for scientists to study its glacial topography, meteorology and changes over time. Currently, topographic data exist for only a few glaciers while no data exist for the vast interior of the ice fields. Velocity has been measured on only five of the more than 100 glaciers, and the data consist of only a few single-point measurements.

The interferometry performed by the SIR-C/X-SAR was used to generate both a digital elevation model of the glaciers and a map of their ice motion on a pixel-per-pixel basis at very high resolution for the first time. The data were acquired from nearly the same position in space on October 9, 10 and 11, 1994, at L-band frequency (24-cm wavelength), vertically transmitted and received polarization, as the Space Shuttle Endeavor flew over several Patagonian outlet glaciers of the San Rafael Laguna. The area shown in these two images is 50 kilometers by 30 kilometers (30 miles by 18 miles) in size and is centered at 46.6 degrees south latitude, 73.8 degrees west longitude. North is toward the upper right.

The top image is a digital elevation model of the scene, where color and saturation represent terrain height (between 0 meters and 2,000 meters or up to 6,500 feet) and brightness represents radar backscatter. Low elevations are shown in blue and high elevations are shown in pink. The digital elevation map of the glacier surface has a horizontal resolution of 15 meters (50 feet) and a vertical resolution of 10 meters (30 feet). High-resolution maps like these acquired over several years would allow scientists to calculate directly long-term changes in the mass of the glacier. The bottom image is a map of ice motion parallel to the radar look direction only, which is from the top of the image. Purple indicates ice motion away from the radar at more than 6 centimeters per day; dark blue is ice motion toward or away at less than 6 cm per day; light blue is motion toward the radar of 6 cm to 20 cm (about 2 to 8 inches) per day; green is motion toward the radar of 20 cm to 45 cm (about 8 to 18 inches) per day; yellow is 45 cm to 85 cm (about 18 to 33 inches) per day; orange is 85 cm to 180 cm (about 33 to 71 inches) per day; red is greater than 180 cm (71 inches) per day. The velocity estimates are accurate to within 5 millimeters per day. The largest velocities are recorded on the San Rafael Glacier in agreement with previous work. Other outlet glaciers exhibit ice velocities of less than 1 meter per day. Several kilometers before its terminus, (left of center) the velocity of the San Rafael Glacier exceeds 10 meters (32 feet) per day, and ice motion cannot be estimated from the data. There, a revisit time interval of less than 12 hours would have been necessary to estimate ice motion from interferometry data. The results however demonstrate that the radar interferometry technique permits the monitoring of glacier characteristics unattainable by any other means.

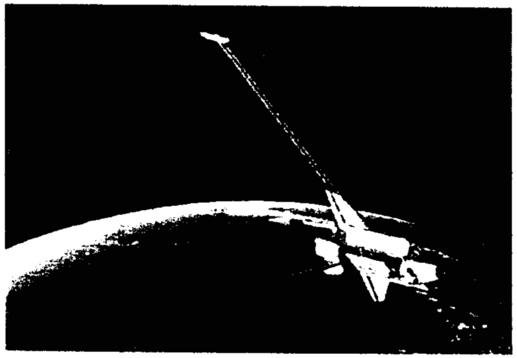
Applications of Radar Technology

Mission Design Approach



Radar Component Development

AirSAR Validation



Shuttle Demonstration

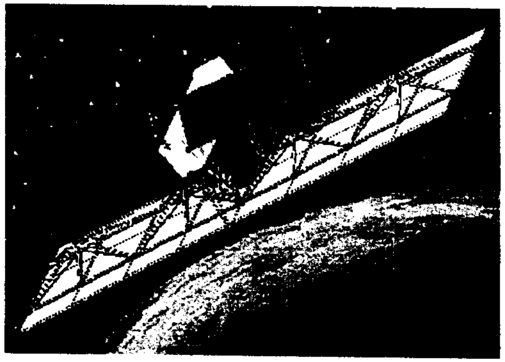
Free-Flyer Interferometric SAR

Applications of Radar Technology

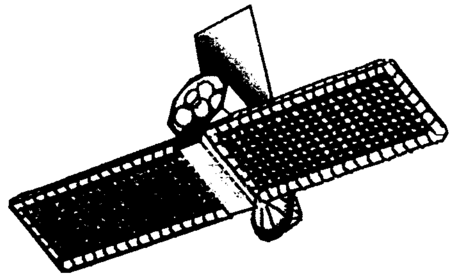
Radar Miniaturization

State-of-Art SAR

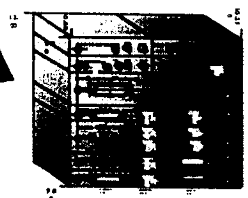
320 kg
1350 W
$65M

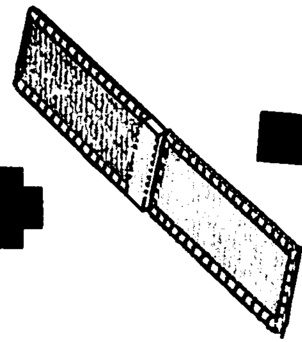


Future SAR



75 kg
450 W
$20M





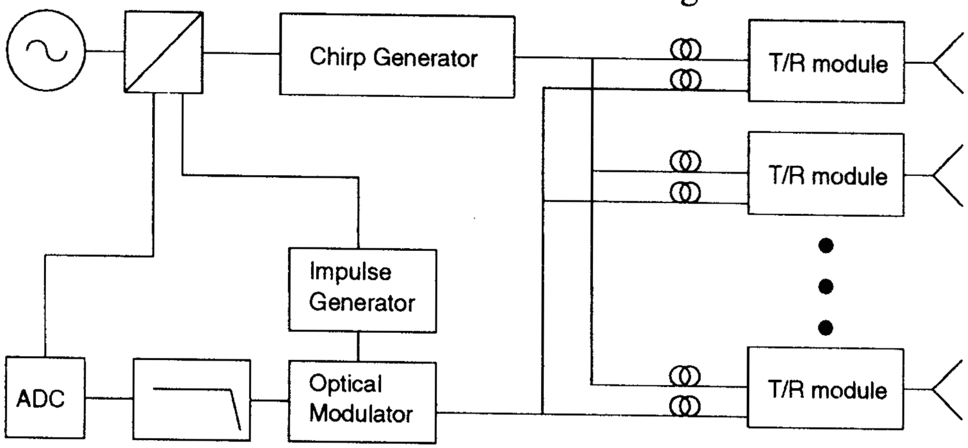
Conversionless Radar
On-Board SAR Processor

Inflatable membrane antenna
framed membrane antenna
Membrane T/R module
Class-E amplifier

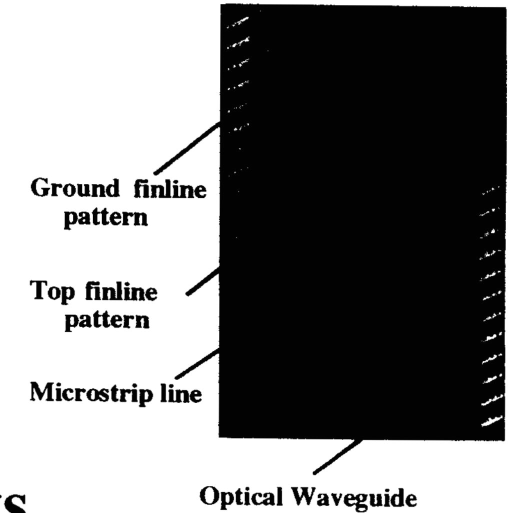
Applications of Radar Technology

Conversionless Radar

Conversionless radar block diagram



Monolithic array of polymer optical modulators



Characteristics

- Optically generated microwave chirp using switched optical time delays
- Switching rate independent of center frequency
- Direct sampling of received signal
- Eliminates local oscillators and mixers traditionally used to up and down convert transmit and receive signals
- Can be used to implement true time delay beam steering

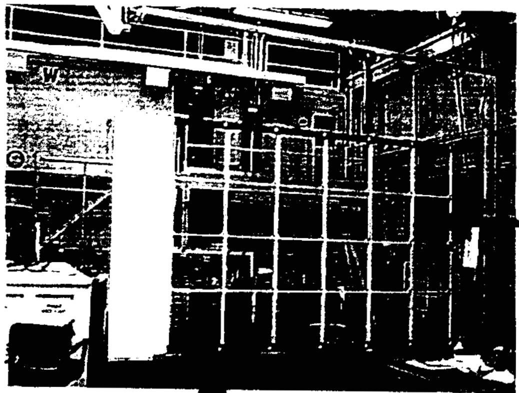
Benefits

- Wide chirp bandwidths
- Low mass and power
- Low complexity
- Well suited for photonically controlled active arrays
- Up to 110 GHz operating frequency using polymer modulators
- Applications include SAR, atmospheric radars, high resolution altimetry

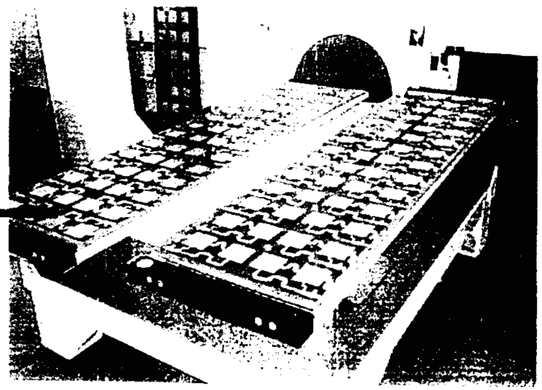
Applications of Radar Technology

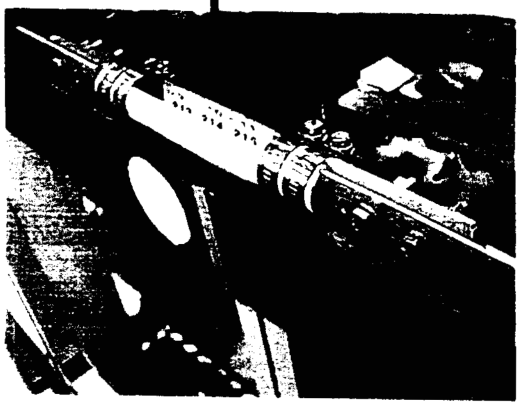
Fold-Up Framed Membrane Antenna

Lightweight Fold-up Composite Planar Frame

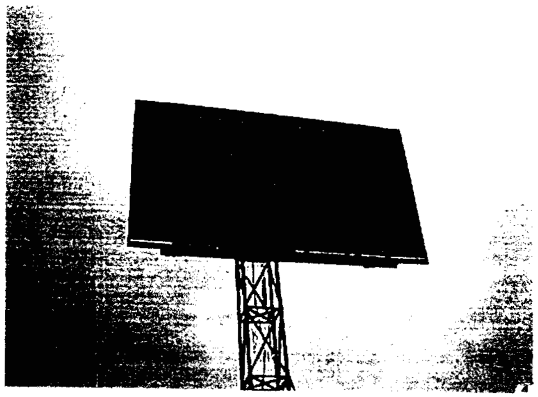


Multiple Layer Framed Membrane Aperture





Spring-Tape Hinge for Pre-Loaded Deployment



Full Framed Membrane Antenna

Characteristics

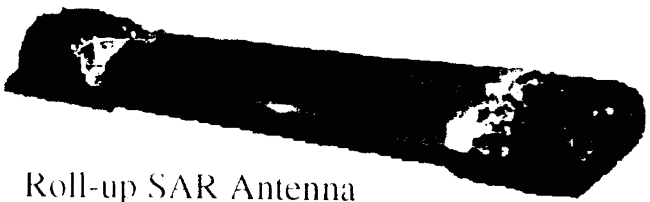
- Mass density: <3 kg/m^2
- L-band with 80 MHz bandwidth and dual linear polarizations
- 85% radiation efficiency with good sidelobe (-13 dB) and cross-pol (-20 dB) levels

Benefits

- Spring tape hinges are lightweight, compact, inexpensive, reliable and space qualified
- Pre-loaded hinges act as both deployment and latching mechanisms, requiring no active deployment device
- Greatly improved the spring-tape hinges by incorporating damping in them
- Integratable with T/R modules for electronic beam scan in two principal planes

Applications of Radar Technology

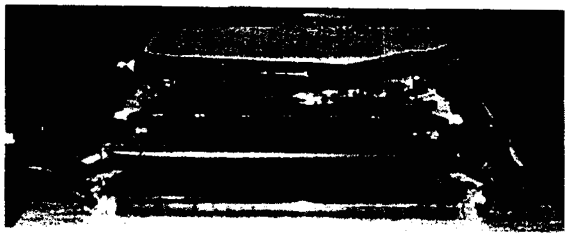
Roll-up Inflatable Membrane SAR Antenna



Roll-up SAR Antenna
(stowed)

Characteristics

- Roll-up inflatable planar frame structure
- Inflatable/rigidizable reinforced aluminum laminate boom
- 3 layers of stretched membrane to form RF aperture
  (5 micron copper on 2 mil Kapton)
- T/R module distributed on central support for 1-D scanning
- Frequency: 1.25 GHz; Bandwidth: 80 MHz
- Polarization: dual linear
- Gain:26.7 dB; Efficiency: 74%
- < $2 kg/m^2$ mass density



Roll-up SAR Antenna (partially deployed)

Roll-up SAR Antenna (deployed)

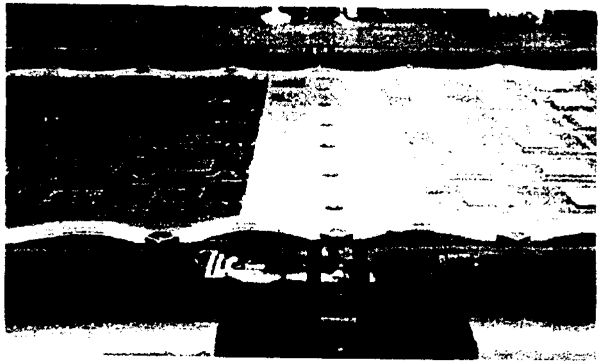
Benefits

- Mass reduction from 23 kg/m^2 to 2 kg/m^2
- High reliability deployment
- High packaging efficiency/small launch vehicle
- Low production cost
- Applicable to most SAR missions
- Scalable to other frequencies up to Ka-band

ILC DOVER

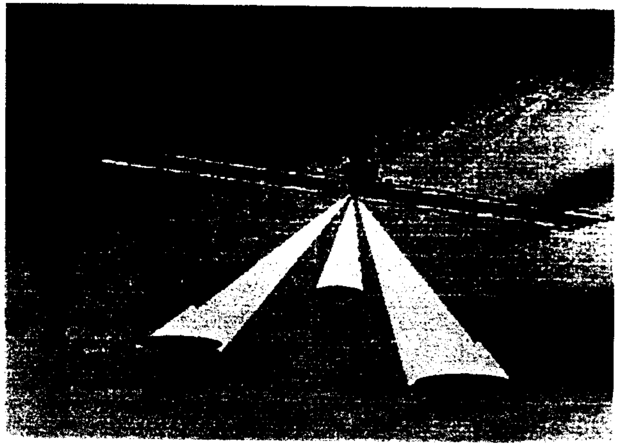
Applications of Radar Technology

Membrane Compatible T/R Module



Inflatable membrane antenna

Flexible T/R Module



Benefits:

- Agile 2-D beam scanning
- High efficiency T/R with local thermal management
- Low-cost manufacturing process

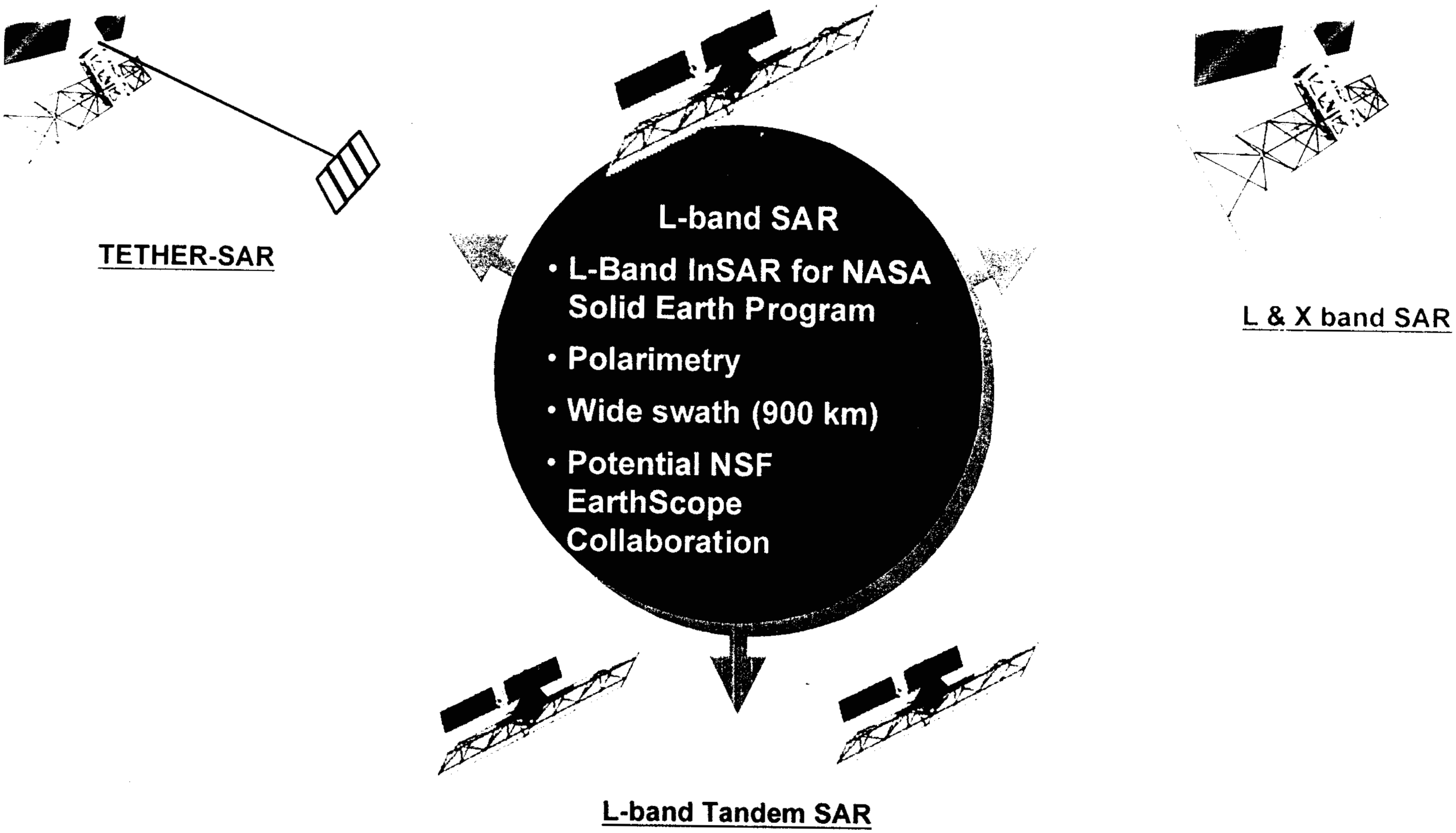
Characteristics:

- MEMS device fabrication on flexible Si
- MEMS micro heat pipes
- High-efficiency Class-E SSPA
- Fiber-optics embedded in membrane

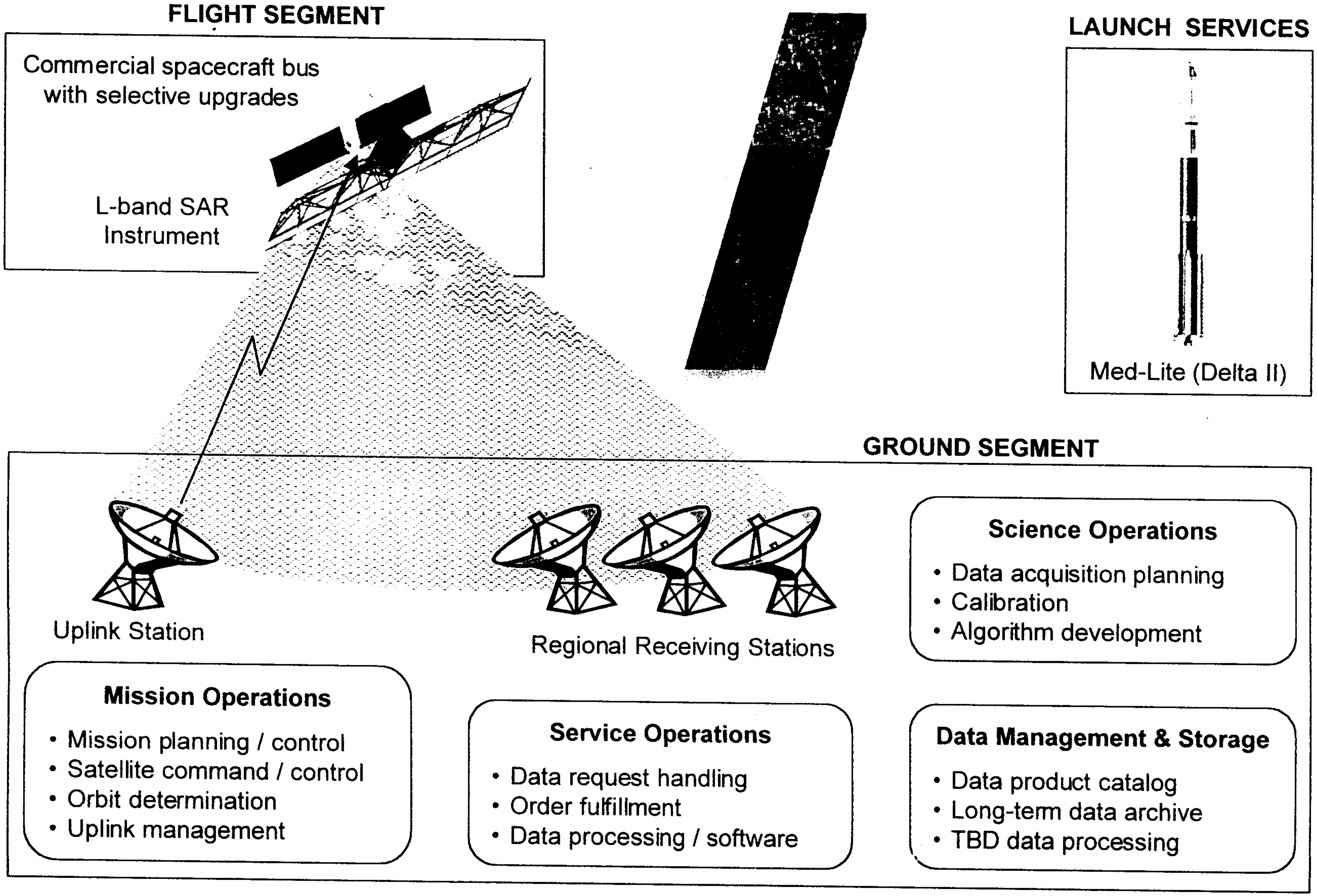
Capabilities/Applications:

- Digital beamforming for planetary landing radar
- Rapid response for high-resolution, wide-swath polarimetric SAR

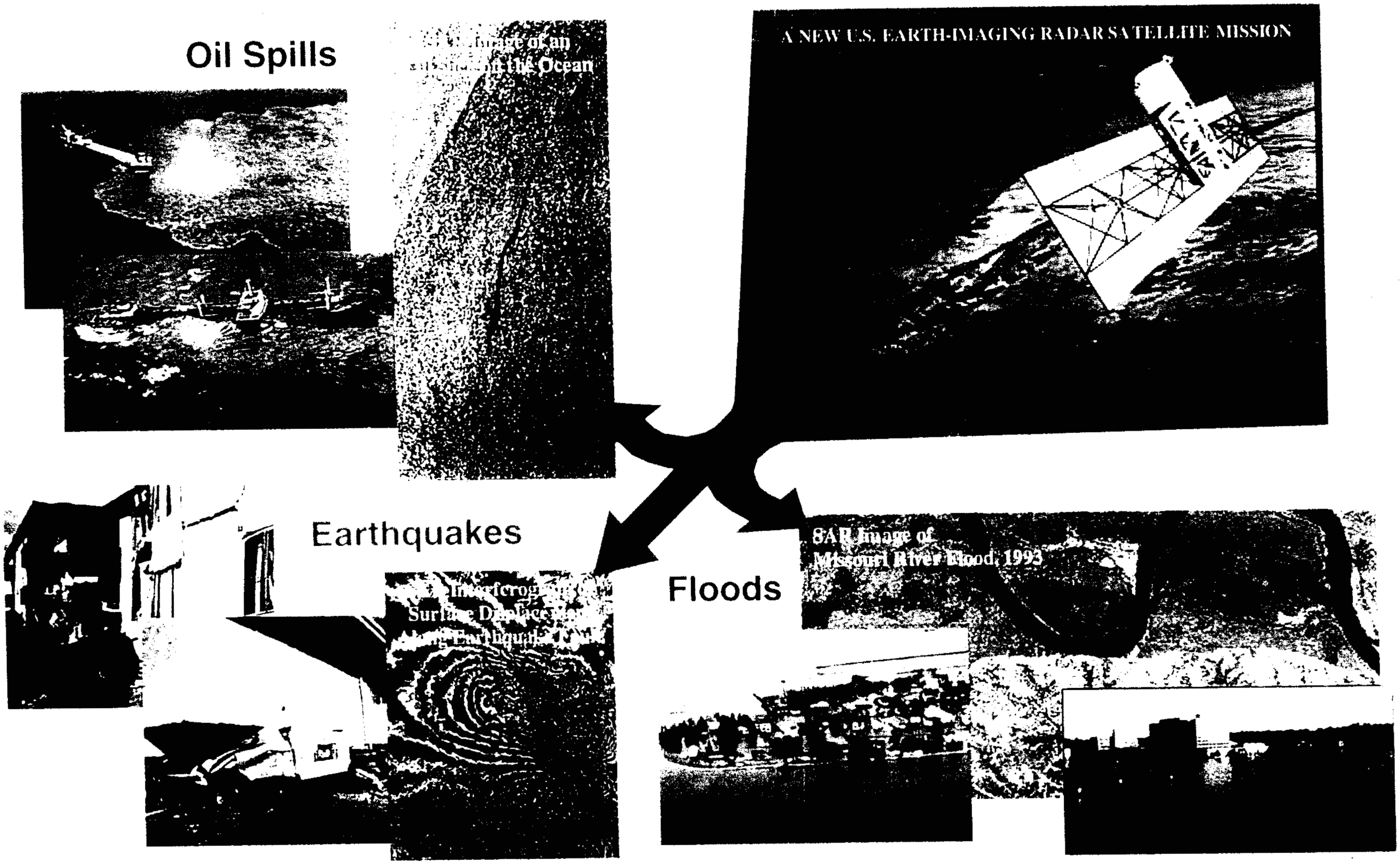
INSAR MISSION OPTIONS



L-SAR MISSION SYSTEM ELEMENTS



DRAMATICALLY IMPROVING OUR NATIONAL CAPABILITY FOR RAPID RESPONSE TO EMERGENCIES



A Synthetic Aperture Radar (SAR) satellite can see through clouds and smoke, and make day and nighttime observations to provide rapid assessments of damage location and extent, even while an emergency is happening